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STUDIES IN SENSITOMETRY. II

ORTHOCHROMATISM BY BATHING

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OBJECT

In a previous paper[1] the writer has referred to the evaluation of color-sensitiveness in photographic plates and has suggested a method for the production of spectrum negatives directly comparable with one another. This second paper deals further with this subject.

The main object of the present work was the investigation of orthochromatic action by bathing-methods, and the means of producing maximum effect throughout the entire visible spectrum with the dyes now at the disposal of the worker in photography. Not only was it desired that the plate be "panchromatic," but it was also sought to be as truly *iso*chromatic as possible; that is to say, equality of deposit for the various regions throughout the spectrum was considered as of primary importance, provided that it was not obtained at too great a sacrifice of speed. This latter consideration therefore eliminates the introduction of any dyestuff whose function would simply be a screening action upon the plate.

Throughout the course of the work certain combinations presenting more than common interest were noted and investigated as they occurred. In no case was any effort made to record a sensitiveness

[1] *Astrophysical Journal*, **25**, 116, 1907.

which required an abnormal exposure when compared with that necessary to obtain full printing density in the blue-violet.[1]

METHOD OF WORK

The sensitizing influence of the cyanins and isocyanins upon gelatin dry plates has been the subject of investigation by a very large number of workers, principal among whom may be mentioned Eder and Valenta, von Hubl, Stenger, König, Mees and Sheppard, etc., and considerable has already been published. The work, however, does not appear to have been sufficiently extended, and it has therefore seemed good to the writer that with a chosen set of dyestuffs all possible combinations should be experimented upon and under variations sufficiently great to render the work comprehensive.

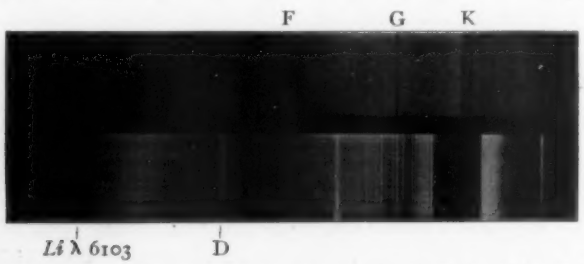
The dyes selected were assigned numbers and divided into groups, the first of which was arranged as follows:

1. Pinacyanol,
2. Pinaverdol,
3. Pinachrom,
4. Homocol,
5. Dicyanin.

With these five numbers as a base the following combinations were made:

1, 12, 13, 14, 15, 123, 124, 125, 134, 135, 145, 1234, 1345, 1235, 1245, 12345,

[1] A note may be interpolated here upon the fallacious results obtained with bright-line, discontinuous spectra in the estimation of chromatic sensitiveness. It is possibly as true as it is practical that if a plate can be impressed with a radiation of certain wave-length, it is then "sensitive to" such radiation; but it is well known that plates may be



"forced" in exposure, or (what amounts to the same thing) the intensity of the radiation may be so increased that a sensitiveness is recorded in a region to which the plate is, in the narrower but more practical meaning of the word, entirely *in*sensitive. As such an example the illustration appended needs no comment.

2, 23, 24, 25, 234, 235, 245, 2345,
3, 34, 35, 345,
4, 45,
5,

which represent all possible combinations with five figures.

The composition of the preliminary (or "first test") bath was

Dyestuff (1:1000 sol. in alcohol)	2–7cc,
Water	200 cc,
Ammonia	3 cc,

the variable amount of dye solution depending upon the number of components. All plates from this bath were bathed and dried without supplementary washing.

The type of plate selected for bathing was the Seed 27 "Gilt Edge," and the length of bathing was in every case three minutes.

Each of these plates (size $3\frac{1}{4}\times4\frac{1}{4}$ inches) was then exposed to a series of diffused daylight spectra in the "standard" spectrograph[1] for 15 and 30 seconds, and 1, 2, 4, 8, 12, 16 minutes respectively; two supplementary exposures were also made, first, through an aesculin filter absorbing all wave-lengths shorter than λ 3968, the object being the avoidance of false conclusions in sensitiveness due to the overlapping of the second order ultra-violet. The second exposure was made through an ammonium picrate filter whose absorption ended rather abruptly at λ 5200, and with the collimator wedge in position, which displaced the spectrum relatively along the plate, thus bringing the B line about equally distant from the two edges. This latter exposure is of great value in determining *extent* of practical sensitiveness.

From the set of thirty-one "type-plates" thus secured (each containing nine spectra) twenty were selected for continued study as possessing particular interest, and with these the treatment was varied according to Table I.

The assignment of decimals was simply to facilitate the recording of results in the laboratory notebook. For example, type 14.11_e then represents a "27" plate bathed in pinacyanol + homocol, in a bath composed of water + alcohol + ammonia, and washed in alcohol; the subscript *e* refers to temperature and will be considered presently.

[1] For description of this instrument see former paper, previously referred to.

TABLE I

Basic Constitution of Dye Bath	Subsequent Washing
0.1 Water	No washing
.2 Alcohol	No washing
.3 Water + Alcohol	No washing
.4 Water + Ammonia	No washing
.5 Alcohol + Ammonia	No washing
.6 Water + Alcohol + Ammonia	No washing
.7 Water	Water
.8 Water + Alcohol	Dil. alcohol
.9 Water + Alcohol	Alcohol
.10 Water + Ammonia	Water
.11 Water + Alcohol + Ammonia	Alcohol
.12 Water + Alcohol + Ammonia	Dil. alcohol
.13 Water + Alcohol + Ammonia	Water
.14 Water + Ammonia	Alcohol

Upon examination, this large number of plates was capable of furnishing very authoritative information upon certain combinations, which were therefore isolated and subjected to further study by varying the amount of dye in the component parts of the combination.

The influence of temperature of the bathing-solution and washing-bath was also investigated at temperatures ranging from 12° to 30° C., at which latter point the gelatin film partially dissolved, the series of subscript letters already referred to indicating the temperatures.

$a = 12°$ C.
$b = 15$
$c = 18$
$d = 20$
$e = 23$
$f = 24$
$g = 26$
$h = 30$

A second group of dyestuffs, consisting of

6. Orthochrome T.,
7. Cyanin,
8. Ethyl Violet,
9. Tetraiodofluorescein,
0. Ethyl Cyanin T.,

was handled in a similar but less extensive manner to Group 1 (twenty plates being made), and deductions from the spectra obtained thereon

allowed of a further reduction to ten, as showing probable interest in combination with the secondary and final selections of Group 1. These combinations were in turn made up, plates again bathed, and the spectrum photographed.

Besides the dyestuffs arranged in the two groups already referred to, a large number of others[1] were also experimented with in combination with those contained in Groups 1 and 2, but only such as present interest in connection with the main object of the present investigation

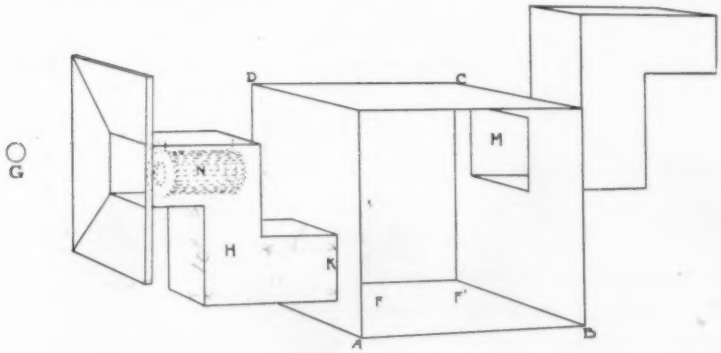


FIG. 1

are referred to throughout the succeeding portion of this paper. It may be stated, however, that the total number of plates exposed numbered 287 besides 40 for acetylene duplication and speed determination aggregating over 2500 separate exposures.

DRYING-CABINET

The bathing of all plates was conducted in total darkness (time being kept by means of an indicating metronome) and dried in a cabinet constructed especially for that purpose, and which may now briefly be described. Reference to the drawing will make the description sufficiently plain.

ABCD (Fig. 1) is a box closed in front by a light-tight door *E*, and containing two racks *FF'* in which were stood the plates to be

[1] Among the remaining dyes experimented with during the course of the present work may be mentioned Pinachrome Blue, Echt Rot, Rose des Alpes, Fluorescein (Monobromo-, Diiodo-, Tetrabromo-), Glycin Red, Acridin Yellow, Chinoline Red, Benzo Green, etc.

dried. A constant current of air, supplied by an electric fan at *G*, was driven through the rectangular elbow-tube *H*, and entered the box proper at *K*, passed between and over the plates at *FF'* and thence through *M* to the outer air. A skeleton coil of German silver resistance wire at *N* was supplied with current, and by this means the incoming air was heated and dried. In use the fan was boxed in by a rectangular wooden frame covered with muslin, which in practice served well to eliminate any trouble due to dust. The resistance coil was so wound that the heat generated in the drying-box averaged 32° C. after running for 30 minutes.[1] Separate switches for the fan and coil enabled either to be "cut in" independently.[2]

CHECK-PLATES AND SPEED

Examination of the final plates as to fitness for measurement also indicated the most interesting types, and of all plates thus selected their corresponding dye baths were again made up and a new series of plates bathed therein under precisely similar conditions as accorded with the former set. These plates were then cut in half; one section was exposed to the spectrum of a constant acetylene flame for a series of exposures of 1, 2, and 3 minutes while the spectrum of diffused daylight was impressed for 2 and 4 minutes at the top and bottom. The daylight spectra on this duplicate set served for two purposes: (1) as position indicators by means of the Fraunhofer lines, and (2) as a check upon the plates already noted in the first series. The acetylene flame spectrum simply served to show that the plates were *relatively* as noted, but cannot of course serve for measurement except between themselves, on account of the difference in chromatic intensity between this light and daylight.

The remaining section of the plate was exposed to daylight in the rotating sector machine,[3] together with an unbathed "27" plate of the same emulsion number, and they were developed together. From

[1] The wire used was B. and S. gauge No. 34, and the amount was approximately 20 ft.; the current was 110 volts, direct.

[2] The importance of rapid drying of battered plates has been pointed out by von Hubl (*Das Atelier*, 1906, p. 6) and also by E. Valenta (*Photo. Korr.*, September 1907) (also, *Brit. Jour. Phot.*, 54, 751, 1907). The drying-cabinet in use by the writer was constructed in July 1903, and has been in use since with unvarying success.

[3] See "Studies in Sensitometry. I," by the author.

this exposure was extracted the relative speed. In practice *three* bathed strips and one "27" were exposed and developed simultaneously.

After checking up the daylight plates with their corresponding acetylene plates, the former were measured in the spectro-photometer and their densities plotted as ordinates against wave-lengths as abscissae, selecting that spectrum exposure on each plate which corresponded to an approximate density of 2.5 in the blue-violet.

As has been stated, it is not intended to detail the results from all of the plates thus obtained, but instead, reference will be made to but two classes, viz., those which possess primary importance because of sensitiveness throughout the entire spectrum, and those which are important by reason of special sensitiveness for a limited spectral region. In both instances the relative sensitiveness-ratios are tabulated for as many positions as may be necessary to convey truthful impression of the results, while particular cases are subject to more complete measurement and graphically illustrated by their accompanying curves.

EVALUATION OF χ

It must be pointed out that while, at first sight, the value for χ has been recorded in apparently the same manner as pursued by Mees and Sheppard, viz., $\frac{\text{blue-sensitiveness}}{\text{yellow-sensitiveness}}$,[1] yet the value is arrived at in a somewhat different way, for while these workers obtain it as $\frac{\text{yellow-inertia}}{\text{blue-inertia}} = \frac{\text{blue-sensitiveness}}{\text{yellow-(or red) sensitivenes}}$, the value of such inertia having been obtained behind broad-banded filters, the present χ value is obtained from the ratio of the *densities* measured directly from the spectrum plate, and hence, relatively speaking, replaces qualitative values by quantitative. Thus, in the present instance

$$\chi = \frac{\text{density of blue at } \lambda\ 4100\ (=\beta)}{\text{density of } \lambda_n}.$$

It will therefore be noted that the lower the value of χ the higher the chromatic sensitiveness.

The shift in sensitiveness toward the red from the point of maxi-

[1] First advanced by Eder, *Beiträge zur Photochemie*, III. Theil, 126; also *Système de sensitométrie*, p. 133.

mum absorption of the dye, following Kundt's law,[1] and due to the high refractive index of the silver salts, has already been noted and commented upon by many writers; also, in view of the fact that the absorption of these later dyestuffs is very definitely known, the inclusion of further work upon this point has not been considered necessary.

NATURE OF PLATE USED FOR BATHING

It is a point often emphasized that there should be selected for bathing a plate which is originally "fog free," and several writers have advocated the use of slow plates as being conducive to the best results. In the course of the present work there were included Seed and Cramer lantern-slide plates, Seed "26x," Seed "23," Seed "process," and Cramer "Crown," besides special instances where use was made of Cramer "Instantaneous isochromatic" and Cramer "Trichromatic." The results from these plates, coupled with experience gained in plate-bathing and covering a period of fourteen years, lead me unhesitatingly to the rejection of slow plates as being wholly unsuited to the end in view.

It goes without question that initially the plate selected must be free from fog, but after the best possible effect has been obtained, i. e., the lowest value for $\frac{\beta}{\lambda_{RED}}$, it still follows that the point of maximum sensitiveness of any plate, due to the silver salts, will not be materially shifted from its original position unless (1) the dye taken up by the silver bromide and gelatin be in such amount that it exercises a selective screening effect upon the light incident upon its surface, or (2) by the introduction of some dye which (otherwise inert) is present solely for the purpose of acting as a color-filter.[2]

Eliminating from the discussion this latter phase,[3] and considering the former modified by the fact that the amount of active dye intro-

[1] A. Kundt, "Ueber den Einfluss des Lösungsmittels auf die Absorptionspectra gelöster absorbirender Medien, *Annalen der Physik*, 4, 53, 1878. See also Eder and Valenta, *Beiträge zur Photochemie*, III, 35.

[2] E. König, "Non-screen Orthochromatic Plates by Bathing," *Brit. Jour. Photo.*, 54, 786, 1907.

[3] Plates for astronomical and general scientific use must be of as high a speed as possible, whence it is impractical (from this standpoint) to consider the presence of a "screening" dye, as its action "slows" the plate.

duced is limited by reason of its negative sensitizing effect when in excess, we find the question considerably narrowed. It follows, then, that not only must the plate be free from fog, but it must also be so chosen that its development-factor for blue-violet light ($\gamma_{\infty\beta}$) be as low as possible; by this means we are enabled to attain the maximum of development action without excessive density in the blue-violet, and hence a more uniform action throughout the spectrum.

DEVELOPMENT

In but little of the work hitherto published is any mention made of the adoption of precautionary measures to insure the constant value of the factors controlling development. It is known that variation in development-time, temperature, or constitution will undoubtedly affect the values of the spectrum-curve, so that unless these constants be kept very rigorously exact, the value of the result will be vitiated to a greater or less extent depending upon the amount of variance. Throughout this work, therefore, the development of all plates was kept constant in constitution of developer and time of development, while the use of a water-bath of 70 liters capacity fitted with electric control assured steady temperature. The development tank is of thin glass, rectangular in shape, and all plates were handled and developed in total darkness.

Some consideration may now be given to the correct duration of development. It will be obvious that if any plate which possesses a high γ_∞ for the blue-violet region receives the minimum of exposure, it may, by continued development, be made to give the required density in that region without showing the true relative color-effect. On the other hand, the same plate may be exposed until the blue-violet region has reached the overexposed portion of the characteristic gradation-curve, and yet from development with a weak reducer, or from lack of sufficient length of development-time, it may in its densest part record a value even lower than the 2.5 necessary. Both plates would be equally untrue when considered as a record of relative sensitiveness.[1]

[1] J. Precht and E. Stenger, "Die Farbenwerte auf panchromatischen Platten in ihrer Abhängigkeit von der Entwicklungsdauer," *Zeitschrift für wissenschaftliche Photographie*, 3, 67, 1905.

Hurter and Driffield have shown[1] that in the gradation-curve of a photographic negative the true relation of the original light-values is obtained only when the development factor (γ) of the negative equals 1.0. If lower than 1.0 then the tonal values will be reproduced with too small a difference between them, while if greater than 1.0 then the differences will be exaggerated. At the same time it must not be lost sight of that the production of a negative is not the final stage in the photographic process, but merely the means to an end, which "end" is a positive proof whether it be on glass or paper. It is also a well-recognized fact that different positive processes require a different type of negative, i. e., more or less "contrasty," or, correctly speaking, of different γ value.

The greater the amount of development action (within limits) which a well-exposed plate receives, the higher becomes the value of the γ. In the recording of scientific data development is often forced in the endeavor to bring out faint detail which lies beyond the period of the straight portion of the characteristic curve, and is located in the region of underexposure, with the result that the more exposed portions of the plate become abnormally dense, and are generally subject to a later local reduction. In sensitometric tests, however, it is obvious that development should not be continued beyond the point where it is possible to reproduce the scale of values in its entirety.

It would appear, therefore, if $\gamma_{1.0}$ means that throughout the "straight" portion of the plate curve, the deposits are proportional to the logarithm of the light received, that such a value would be correct for the development of the spectrum exposures. Theoretically, the simplicity of such a solution is marred by the fact that it has been shown that the gradation-curve varies slightly with the wave-length of the light; so that it results from this that if $\gamma = 1.0$ at, say, the blue region, then in the yellow the value may be, say, $\gamma_{1.1}$.[2] In practice, however, the objection may be dismissed, as the variance involved is

[1] *Jour. Soc. Chem. Indust.*, May 31, 1890.

[2] Mees and Sheppard, in their *Investigations on the Theory of the Photographic Process* (Longmans, Green & Co., 1907), p. 307, arrive at the conclusion that γ remains unaltered by different wave-lengths, the alteration existing merely in the *shape* of the curve, and due principally to differences in the optical opacity of the film, resulting from different colored lights. See also article by E. Stenger, *Zeit. für Reproductionstechnik*, March 1906.

exceedingly small, and in work of this nature, when handled in the method proposed, becomes a vanishing quanity.

The great number of positive printing-media now available are called forth principally by the necessity of supplying the general worker with a means of obtaining presentable results from negatives which, from many reasons, have been improperly exposed or developed. In sensitometric work uncertainty of exposure and development has been eliminated, so that it simply remains to consider the process best suited for use. Such process is unquestionably that of a positive upon glass, and, therefore, the γ value of the negative must be altered to suit the capacity of the process, the amount and direction of such alteration depending upon the medium selected.

Taking only two examples from many media, let us consider development paper, on the one hand, and a transparent positive on glass, on the other.

Three sector-disk negatives were taken which had been developed for different times and had measured development-factor values of $\gamma_{0.87}$, $\gamma_{1.3}$, and $\gamma_{2.5}$ respectively. All three were printed simultaneously on "portrait velox" for 4, 6, 10, and 16 seconds, exposure being to a constant light-source. All four prints were then developed in rodinal.

Examination showed that it was possible to reproduce only one of the negatives so that all of the tones would show, viz., $\gamma_{0.87}$, the remaining two being too "contrasty," so that in printing for the tones involved in the higher densities, the other end of the scale was lost. A transparency, however, on a Seed "27" plate gave a complete scale of tones up to about 5.0 H. and D. units ($\gamma_{2.5}$).[1]

Now, if it be possible to print from a negative showing all tones between 0 and 5.0 it should (theoretically) be practical simply to develop the plate containing the series of spectrum exposures at the temperature and for the time necessary to reach a development-factor value of approximately 2.5. Objection to this course lies in the fact that although it is possible to measure in the neighborhood of this density, yet there is in the hands of the writer an unreliability attendant upon such measures, and they are rendered possible only by the intro-

[1] The value of 5.0 was obtained by extrapolation, this density being too high for measurement without the use of special methods.

duction of a supplementary measured density plate in the polarized beam. For convenience, therefore, and as being conducive to more reliable results, direct measurements are not made upon a density of higher value than approximately 2.5. Inasmuch as the slope of the gradation-curve is dependent principally upon the amount of development action, it suffices, then, that the spectrum plate be developed with the same developer, for the same length of time, and at the same temperature, as the sector-disk plate of same constitution which when measured records a value of $\gamma_{1.3}$. This method, although not absolutely exact, is sufficiently near truth to be accepted, when we take into consideration the accidental errors of the evaluation. By exposure of a plate of similar nature through narrow-banded filters it would be possible to obtain sensitiveness values for various limited regions, which with reference to the blue-sensitiveness could be easily calculated into a mean γ_n for use with the spectrum plate; but such a method would be a refinement possessing no truly practical value, and would require to be redetermined for every variation in the sensitizing bath.

It may be stated that a Seed "27" plate exposed to daylight in the sector-disk machine requires 3 minutes' development at a temperature of 20° C., with a solution of rodinal 1:24, in order to attain $\gamma_{1.3}$.

TEMPERATURE

The influence of the temperature of the sensitizing bath upon the plate was studied by making up bath 124, which was cooled by means of ice to a temperature of 12° C., and in which were then bathed two plates for 3 minutes and subsequently washed in alcohol at similar temperature for 30 seconds. The temperature of the bath was then raised by seven separate stages to 30° C., two plates being bathed at each step in the rise. All plates were then rapidly dried at the same temperature.

Exposure of each plate to the spectrum series of a constant acetylene flame showed a very interesting and clearly defined difference, which was borne out by a second series bathed on the following day and exposed to diffused daylight.

The following are the measurements of the principal plates in the series:

Temperature	Mean Density			$\chi=\frac{\beta}{\lambda\ 6500}$
	At λ 6500	At λ 5900	At λ 4300	
12°.....	1.3500	1.2440	2.3128	1.71
20°.....	2.1370	1.8160	2.2502	1.05
24°.....	1.8660	1.5206	1.7686	0.95
30°, plate melted.....				

and their accompanying curves (Fig. 2).

It therefore follows from the foregoing results that an increase in the temperature of the dye bath exercises a beneficial effect upon the relative chromatic sensitiveness of this plate. This effect has been confirmed in many other instances throughout the course of the investigation. The temperature of the bath is therefore kept constant at 23° C. Referring to the plates of different makes which have also been experimented with in this regard, it results, that although the effect is not identical with each, it yet appears to be uniformly certain with the Seed "27."

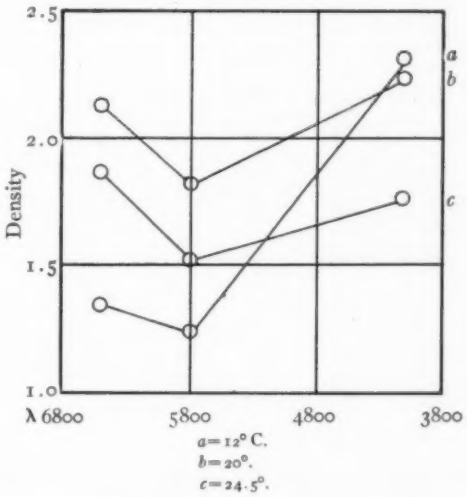


Fig. 2.—Acetylene flame (relative densities not comparable with other curves).

RESULTS

The principal results may now be briefly considered as follows:

Pinacyanol.—A plate bathed in an aqueous solution of this dye and washed in H_2O shows a strong sensitiveness to the spectrum from λ 3300–7000, and with increased exposure to beyond λ 7200, with two distinct maxima in the red and green at λ 5270–5800, and λ 6160–6870. The addition of NH_3 to the bath increases the red-sensitiveness to a considerable degree, and this increase is propor-

tional to the amount of NH_3 added. The introduction of ethyl alcohol to the dye bath, and omission of the subsequent washing, results in a distinctly greater action from λ 5270–5890, while the general effect upon the sensitiveness from λ 5270–6580 is shown by a decided increase in relative chromatic effect. A subsequent rinse in alcohol after bathing shows a still further improvement.[1]

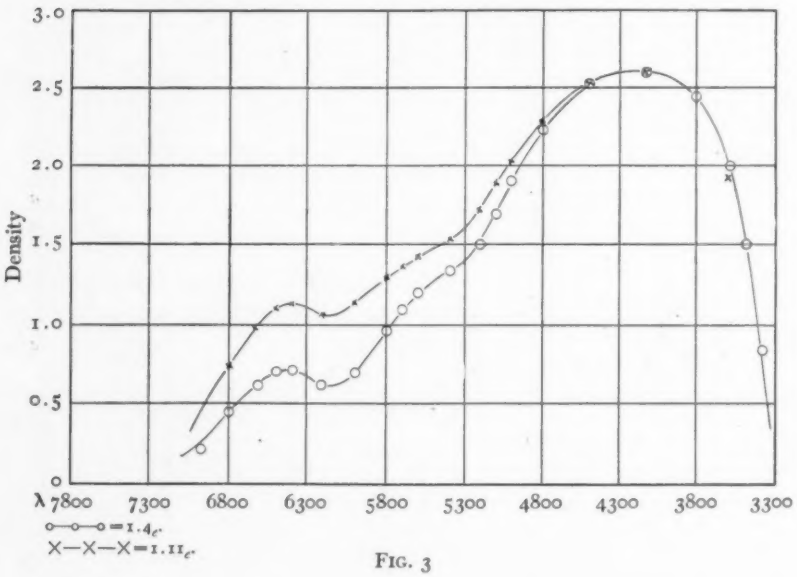


FIG. 3

Variation in the amount of dyestuff entering into the bathing-solution was experimented upon in amounts varying from 30 minims to 90 minims in steps of 10 minims. The greatest sensitizing action upon the "27" plate was found to follow when the amount of dye was $\frac{1}{68000}$ to $\frac{1}{70000}$, which is in close agreement with the experimental results of Mees and Sheppard.[2]

Fig. 3 shows the curve of this type-plate and illustrates the advantageous results following the addition of, and washing with, alcohol. The reduction in speed from the "27" is 0.19.

[1] The introduction of alcohol to the dye bath was published by Dr. E. König, who however treated the plate to a subsequent washing in water. *Photo. Korr.*, September 1905, p. 406.

[2] *Theory of the Photographic Process*, p. 327.

In obtaining the χ value for all of the following plates $\left(\frac{D\beta}{D\lambda_n}\right)=\chi$, $\lambda\,4100=\beta$, while $n=\lambda\,5100$, 5500, 5900, 6300, and 6800 respectively.

χ FOR PINACYANOL BATHED

Type \ λ	6800	6300	5900	5500	5100
1.11$_c$.....	3.47	2.34	2.15	1.75	1.38
1.4$_c$.....	5.79	3.76	3.25	2.01	1.53

Pinaverdol.—This dye in dilute alcohol bath sensitizes for the green and orange-red of the spectrum extending to about λ 6400 (and with increased exposure to λ 6700), with two broad distinct maxima near

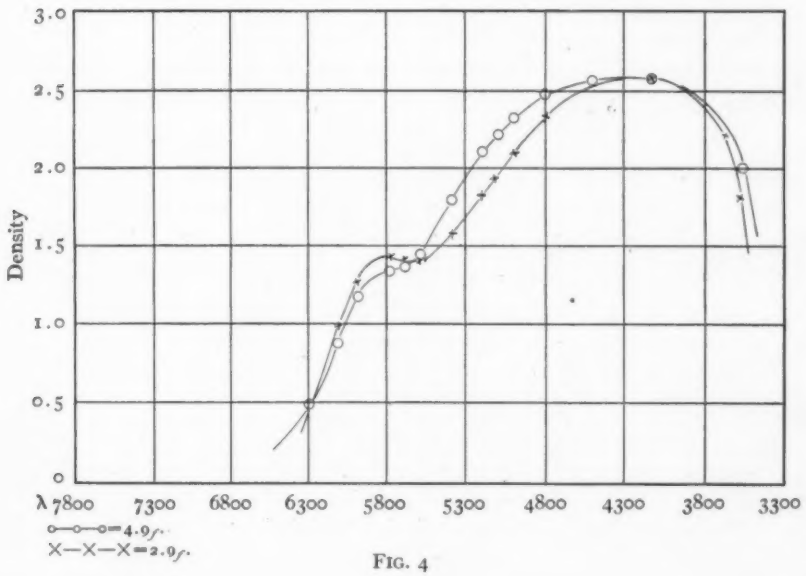


FIG. 4

λ 5900 and λ 5300. The best result from the use of this dye was obtained with a bath of the following constitution:

Pinaverdol 1:1000	60 minims
Methyl Alcohol	3 oz.
Water	4 oz.
Ammonia	60 minims

Time of immersion, three minutes—no washing. Speed difference = 0.60. See 2.9*f*, Fig. 4.

At λ=6300	5900	5500	5100
χ=5.73	1.79	1.75	1.31

Homocol.—This is a particularly interesting sensitizer for the green on gelatino-silver-bromide, embracing the entire region from λ 4860–5460, and when made up with dilute ethyl-alcohol bath followed by alcohol washing gives a plate working with exceptional clearness. Its action is very similar to pinaverdol although with equal exposure it does not sensitize so far into the red. As a sensitizer for the blue-green this dye has no equal (see Fig. 4, curve 4.9*f*).[1] Speed difference =0.61.

At λ=6300	5900	5500	5100
χ=5.20	1.97	1.60	1.17

Pinachrome.—In dilute ethyl alcohol plus ammonia bath this dye sensitizes for the yellow-green and orange and shows definitely the *α* and *β* bands characteristic of cyanin.[2] With normal exposure to the spectrum the sensitiveness extends to λ 6300 but can be forced to beyond λ 6500 (Fig. 5). Speed difference =0.36.

At λ=6300	5900	5500	5100
χ=25.7	2.01	1.68	1.83

Pinacyanol + pinaverdol.—These two dyes in combination result in a very good plate in which the characteristic pinacyanol gap in the blue-green is very greatly benefited. χ values for the various positions are given in Table A. The gradation values in this plate remain similar to the unbathed "27." Speed dif. =0.32.

Pinacyanol + homocol also forms a good combination and one which has been recommended by Monpillard.[3] When made up in dilute

[1] This curve is not in agreement with that published by Mees, Sheppard, and Newton (*Jour. Roy. Phot. Soc.*, **45**, 266, July 1905). The difference results from the use of a dilute alcohol dye bath in place of an aqueous. An aqueous (ammoniacal) bath gave a similar result up to λ 4500 to that obtained by these workers.

The replacement of the ammonia by potassium carbonate (and other alkalies) as recommended by Dr. König (*Phot. Korr.*, September 1905) did not prove successful in the hands of the writer.

[2] The two absorption bands of cyanin have been termed respectively *α* and *β* by von Hubl. The former lies near λ 5900 while the latter is near λ 5450. Eder's *Jahrbuch*, 1905, p. 183; also *Jour. Roy. Photo. Soc.*, **46**, 133, 1906.

[3] *Bull. Soc. Fran. Phot.* (2), **22**, 132, 1906.

ethyl-alcohol bath without ammonia the action throughout the red and green although fairly even is yet weak when compared with that in the blue-violet. The introduction of ammonia, however, shows a steady gain in the red- and green-sensitiveness as the amount is increased. (The same effect is noticeable as the bathing-time is increased.) With normal exposure the sensitiveness extends slightly

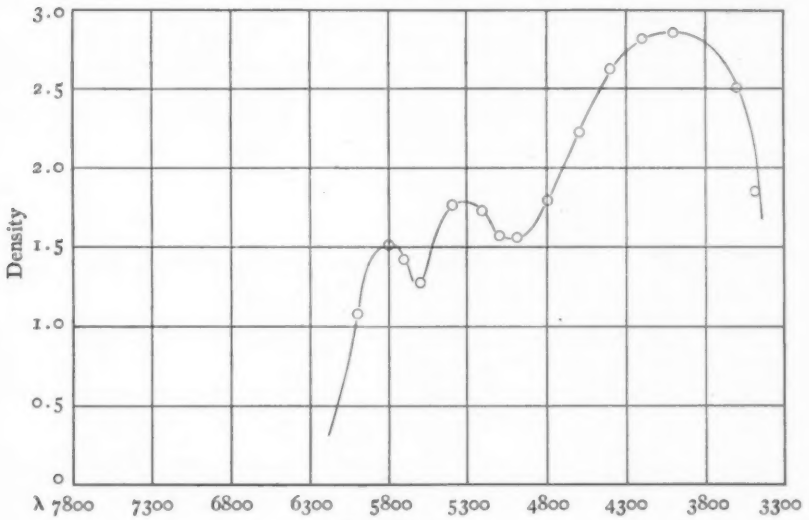


FIG. 5.—(3.11_e)

beyond B (λ 6870) while with increase in exposure it runs beyond *a* (λ 7200). From the blue the chromatic sensitiveness falls off rather abruptly and then pursues a fairly uniform curve which shows two distinct maxima at λ 5800 and λ 6400 respectively. Decrease in the amount of pinacyanol accentuates these maxima, the best result being obtained with a bath composed of

Pinacyanol (1:1000)	60 minims
Homocol	60 minims
Alcohol (ethyl)	3 oz.
Ammonia	90 minims
Water (dist.)	4 oz.

Another bath made up with the same proportionate amounts of dye, but containing a minimum quantity of water and excess of alcohol, shows a peculiar drop in the red-sensitiveness which ends at

λ 6560 very abruptly, and with an exceedingly pronounced drop in the orange at λ 6100, both drops becoming more pronounced as the dyes are increased in amount. A "27" plate treated in this bath resembles very closely in action the Seed "panchromatic" (see Fig. 6). When

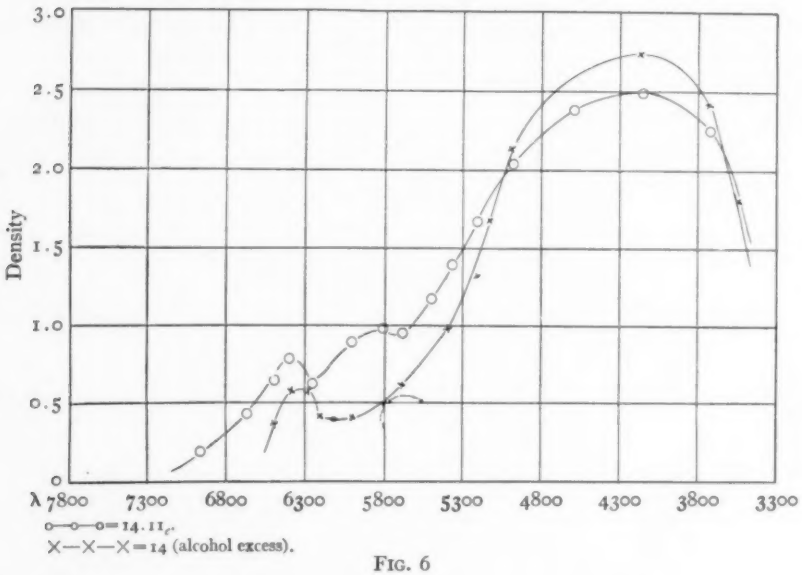


FIG. 6

made up in ammoniacal water bath the sensitizing action is very weak and unsatisfactory; this weakness is still more apparent when the plate is washed in water after staining, but shows a slight improvement when the washing is conducted with alcohol. Speed dif. = 0.74.

χ

Type \ λ	6800	6300	5900	5500	5100
14.II$_{f}$.....	7.01	3.54	2.53	2.09	1.28
14.		4.40	5.91	3.16	1.47
(Alcohol Bath)					

Pinacyanol + pinaverdol + homocol.—This combination when made up in an aqueous ammoniacal bath and without supplementary washing sensitizes a "27" plate for practically the entire visible spectrum, extending easily to λ 7200. The usual gap in the blue-green is entirely

closed and the curve is fairly smooth throughout; washing the plate in water after staining, although increasing the speed, does not add anything to the chromatic value of the plate; a *slight* improvement is effected by an alcohol washing-bath. If the dye bath be made up with alcohol + ammonia the sensitizing action is weak and ill defined, and possesses no value whatever.

If the staining-bath be made up with dilute ethyl alcohol and ammonia we obtain a most excellent plate, with a markedly high red-sensitiveness and evenness of action. A brief washing in alcohol

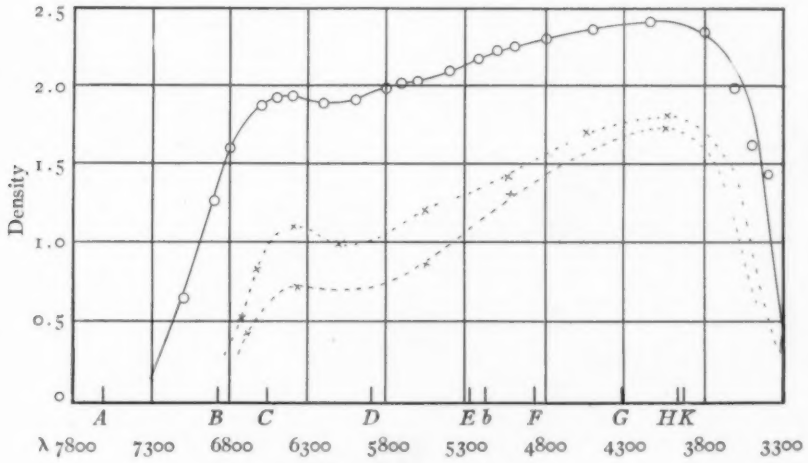


FIG. 7.—(124.11$_c$)

seems to be also very beneficial, no apparent difference showing (after exposure and development) whether this washing be continued for 20 seconds or 5 minutes.

Of all results obtained, this plate is decidedly the best, and for cleanness of working and general freedom from fog it leaves little to be desired. The bathing formula is as follows:

Pinacyanol	1:1000	50 minims
Pinaverdol	1:1000	40 minims
Homocol	1:1000	40 minims
Ammonia		120 minims
Alcohol		3 oz.
Water		4 oz.

Bathing-time 4 minutes; alcohol washing 30 seconds.

Fig. 7 shows the measured curve of this plate together with two underexposure curves showing the relative chromatic effect with reduced exposures; development, of course, remaining constant. Speed dif. =0.17.

TYPE 124.II$_e$. χ

Exposure \ λ	6800	6300	5900	5500	5100
Normal.....	1.51	1.26	1.24	1.18	1.09
A.....	4.72	1.65	1.80	1.45	1.29
B.....	8.75	2.42	2.41	1.92	1.43

Speed difference = 13% in favor of the "27."

Pinacyanol + pinaverdol + dicyanin in ammoniacal water bath gives also a very good plate, although the action of the dicyanin seems to reduce greatly the general integral sensitiveness.[1] The blue-green

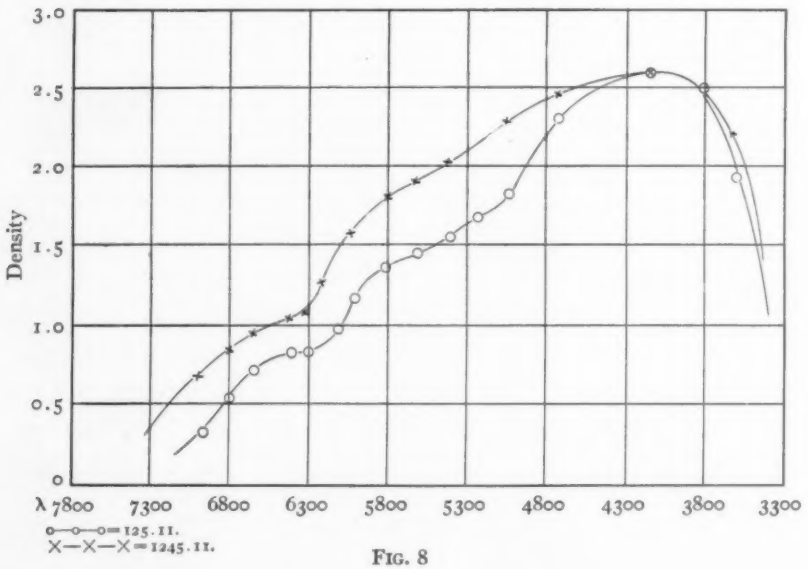


FIG. 8

insensitive gap is closed and the chromatic sensitiveness-curve descends toward the red in a good flowing sweep, the action extending to λ 7200

[1] This lowering of the general plate sensitiveness is noticed and commented upon by Monpillard, *Bull. Soc. Fran. Phot.* (2), **22**, 1906; also *Jour. Roy. Phot. Soc.*, **46**, 261, 1906.

with normal exposure but may easily be forced below Fraunhofer's A; on several plates the action is carried distinctly lower than λ 8400. Washing does not appear to influence the selective action in any way.

When the plate is treated to conform to .11 the sensitiveness to the red at λ 6500 and to the green at λ 5700 is increased, which adds materially to the value of the plate in general, although this increase is at the expense of the blue-green, which loses somewhat in sensitiveness. The plate works clean and bright, but does not keep. For sensitiveness-curve see Fig. 8. Speed dif. = 1.64.

Type 125.11_e

At λ =	6800	6300	5900	5500	5100
χ =	4.72	3.07	2.00	1.76	1.49

The bath formula was as follows:

Pinacyanol	1:1000	30 min.
Pinaverdol	1:1000	60 min.
Dicyanin	1:1000	40 min.
Ammonia		120 min.
Alcohol		3 oz.
Water		4 oz.

Bathing-time = 3 minutes; washing-time = 30 seconds; temperature = 23° C.

Pinacyanol + pinaverdol + homocol + dicyanin.—The introduction of homocol to the previous bath increases to a marked degree the general panchromatic quality and the sensitiveness is rendered much more even, although at the expense of speed (see Fig. 8). Speed dif. = 0.91.

Type 1245.11_f

At λ =	6800	6300	5900	5500	5100
χ =	3.07	2.36	1.53	1.33	1.15

Pinacyanol + homocol + dicyanin.—The use of homocol in place of the pinaverdol in a type .11 bath and with a bathing-time of 4 minutes produces also a very good plate with a distinct lowering in the value $\gamma_{\infty\beta}$. This lowering of the density in the blue region was at first considered due to the solvent action of the ammonia on the silver salts but subsequent experiments seem to point instead to the action of the combined dyes as being the main factor influencing this reduction. This opinion must, however, be accepted with reserve, as sufficient

TABLE II

VALUES OF $\chi = \frac{D\beta}{D\lambda_m}$

Type	Dyestuffs	At λ 6800	At λ 6300	At λ 5900	At λ 5500	At λ 5100	Sensitiveness Limit (Normal Exposure)	Speed Reduction*
15.II.....	Pinacyanol + Dicyanin	6.52	4.10	2.75	2.65	2.11	7600	0.73
123.II.....	Pinacyanol + Pinaverdol + Pinachrom	5.49	3.18	2.20	1.66	1.48	6950	0.23
12345.II....	Pinacyanol + Pinaverdol + Pinachrom + Homocol + Dicyanin	4.22	3.36	2.43	1.83	1.48	7200	1.3
134.II....	Pinacyanol + Pinachrom + Homocol	2.82	2.44	1.79	1.60	1.47	6950	0.19
135.II.....	Pinacyanol + Pinachrom + Dicyanin	4.10	2.90	1.14	1.36	1.52	7200	1.25
1234.II....	Pinacyanol + Pinaverdol + Pinachrom + Homocol	5.40	3.13	2.17	1.71	1.38	7200	0.8
1345.II....	Pinacyanol + Pinaverdol + Homocol + Dicyanin	5.10	3.36	2.01	1.66	1.42	7500	1.0
1235.II....	Pinacyanol + Pinaverdol + Pinachrom + Dicyanin	3.95	3.33	2.31	1.81	1.31	7500	0.42
245.II....	Pinaverdol + Homocol + Dicyanin	5.01	4.07	1.83	1.47	1.07	7300	.61
235.II....	Pinaverdol + Pinachrom + Dicyanin	6.30	3.67	1.87	1.45	1.37	7400	.71
234.II....	Pinaverdol + Pinachrom + Homocol	3.95	2.79	2.14	1.62	1.37	7000	.68
25.II....	Pinaverdol + Dicyanin	5.80	5.75	2.31	1.65	1.37	7100	.81
24.II....	Pinaverdol + Homocol		3.36	1.66	1.38	1.14	6600	.41
23.II....	Pinaverdol + Pinachrom	4.11	3.47	2.0	1.52	1.43	6850	.62
34.II....	Pinachrom + Homocol		3.18	1.82	1.46	1.31	6300	.62
35.II....	Pinachrom + Dicyanin	10.2	5.04	2.52	1.65	1.54	7300	1.14
345.II....	Pinachrom + Dicyanin + Homocol	11.4	5.11	4.0	2.34	1.52	7500	1.11
45.II....	Homocol + Dicyanin	5.45	3.58	2.14	1.65	1.17	7500	
13.9	Pinacyanol + Pinachrom	3.36	2.81	1.77	1.55	1.48	6900	1.27
5.II....	Dicyanin	10.0	12.50	11.32	17.15	4.12	7300	0.94
6.9	Orthochrom T.		11.5	1.62	1.55	1.27	6100	.19
9.II....	Tetraiodofluorescein			13.4	1.74	3.65	5900	.39
0.7	Ethyl Cyanin T.	11.2	1.99	1.65	1.46	1.54	(Too low to be definitely stated)	.76
64.II....	Orthochrom T. + Homocol		10.4	2.09	1.38	1.48	6400	.41
61.II....	Orthochrom T. + Pinacyanol	6.42	3.71	2.17	1.79	1.51	6900	.24
614.II....	Orthochrom T. + Pinacyanol + Homocol	3.10	2.0	1.55	1.66	1.38	7200	.27

* Approximate exposure-time increase to equal Seed "27."

work was not performed to confirm it, the type not being in direct line with the object sought.

The normal sensitiveness extends to λ 7200, although with but slight increase of exposure the great A group is clearly impressed. The plate is foggy if kept over a few days and must therefore be used immediately after preparation. A continued water wash after bathing gives a cleaner and better keeping plate but considerably reduces the

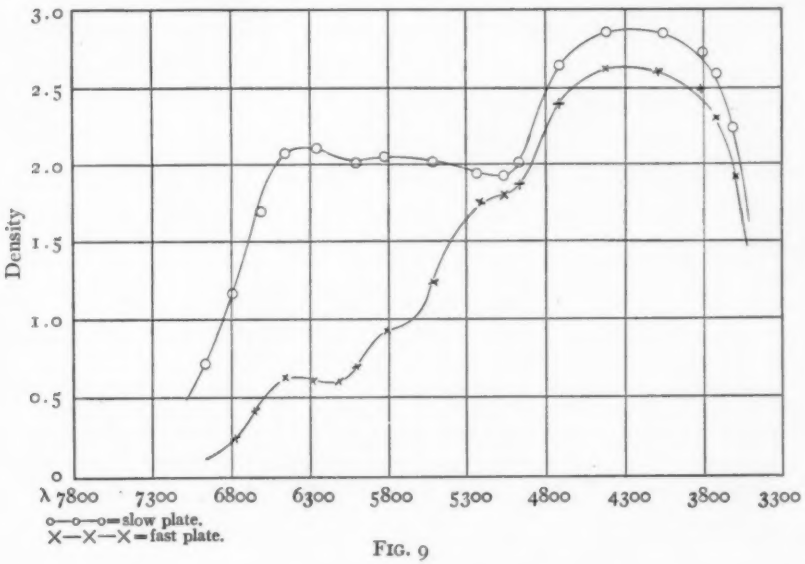


FIG. 9

speed. It may be mentioned that if the dye bath be made up with an aqueous ammoniacal solution (.7) and the plate be not washed after bathing, the same lowering of $\gamma_{\infty\beta}$ may be observed. Speed dif. =0.62.

Type 145.II$_c$. χ

At λ=6800	6300	5900	5500	5100
χ=3.34	2.32	1.82	1.66	1.38

Table II contains the χ values for the remaining plates of interest.

COMMERCIAL BATHED PLATES

Wratten "spectrum panchromatic."[1]—The consideration of orthochromatism by methods of bathing would be incomplete without notice

[1] Wratten and Wainwright, Ltd., Croydon, Surrey, England.

of this comparatively recent addition to the commercial-plate market. Undoubtedly, to the individual without previous experience in plate-bathing there is a certain amount of technical skill required for the successful production of bathed plates of uniform quality. Besides, there is the question of necessary accommodations, such as bathing-tanks and drying-cabinet, which very often prevent the taking-up of the work, more particularly by the individual who has only occasional use for such a product.

It is with the purpose of meeting just such conditions that these plates are prepared, and as they are *bathed* plates, it is proper that their consideration should find a place here.

These panchromatic plates are made in two grades: "fast" and "slow," and from a series of spectrum exposures, handled in precisely the same manner as the plates previously referred to, a series of measurements was made from which were plotted the curves shown in Fig. 9.[1]

χ FOR WRATTEN "PANCHROMATIC"

Type	At λ 6800	6300	5900	5500	5100
Fast	11.6	4.30	3.30	2.12	1.47
Slow	2.41	1.37	1.42	1.42	1.5

When reasonably fresh, the "fast" grade works with vigor and cleanliness, together with good freedom from fog, but like all bathed plates suffers deterioration as it is kept. The sensitiveness is good and at normal exposure pursues a fairly smooth curve extending beyond λ 6870; with increased exposure to beyond λ 7200. A normally exposed plate shows three distinct maxima situated at λ 5150, λ 4850, and λ 6400. The slow panchromatic is characterized by a remarkably low $\gamma_{\alpha\beta}$. There is somewhat of a drop in the blue-green from λ 4860–5150, but from that point the curve rises with great evenness to λ 6600, whence it continues with gradually lowering sensitiveness on to about λ 7500. A is obtained with increased exposure. Unquestionably these are the finest panchromatic plates at present commercially obtainable, and the scientist or three-color worker who cannot prepare his own plates is certainly greatly indebted for the

[1] The writer here desires to express his thanks and appreciation to Dr. Mees, who courteously presented the plates.

enterprise manifested by their production. The inclusion here of their curves of spectral sensitiveness is necessary for purposes of direct comparison with other types under identical conditions.[1]

From the foregoing description and curves it will be seen that by far the best approximation to isochromatism is obtained in type 124.11_e. Further observation upon the behavior of the plate after bathing shows that it follows the general rule by suffering a decline in relative chromatic sensitiveness as its age increases. This retrograde action however is but slight for the first period (extending over several weeks) although distinctly noticeable after the lapse of two months. Measurement of a plate bathed at the same time as that plotted in Fig. 7 but kept for 60 days before exposure, shows a χ-difference as follows:

At λ=6800	6300	5900	5500	5100
$\Delta\chi$=3.09	0.39	.56	.25	.03

from which it follows that in order to obtain the very best effect the plates should be used when fresh.[2]

COMPENSATION FILTER

While the curve shown in Fig. 7 represents the best approximation to a true isochromatic value by means of the judicious selection of plate and dye bath, yet to be *absolutely* correct this curve should be a straight horizontal line. The advantages of a plate possessing such a curve of sensitiveness to those engaged in recording scientific data is sufficiently evident without detailed exposition. To approach this straight-line condition two courses are open: (1) the introduction to the film of a chemically inert dye whose function consists in staining the gelatin and thus acting as a color-filter; or (2) the use of a separate color-filter in the path of the incident light. This latter is (for the present purpose) decidedly the better method, because in the former case the integral speed of the plate is considerably lowered.

[1] The curve of the "fast" panchromatic, together with the χ value for the same, is very comparable with that plotted by Mees (*Brit. Jour. Phot.*, 53, 430, 1906), but only from λ 4700 to the limit of the red-sensitiveness. Owing (presumably) to the light-source, Mees' curve does not represent the true point of maximum sensitiveness, which should be at λ 4100 instead of λ 4700, the usual maximum for *AgBr*.

[2] For several months past this plate has been in almost constant use at this observatory in the records for the photographic photometry of colored variables, with results in every way satisfactory.

Repeating in Fig. 10 the sensitiveness-curve of Fig. 7, and drawing the horizontal path of the new (desired) sensitiveness-curve, we may obtain the extinction coefficient-curve of the color-filter necessary, by means of the simple formula

$$\frac{D-c}{\gamma}=e\,,$$

where D = density of the plate at any given wave-length, c = the proposed new curve of sensitiveness, γ = the development-factor, and

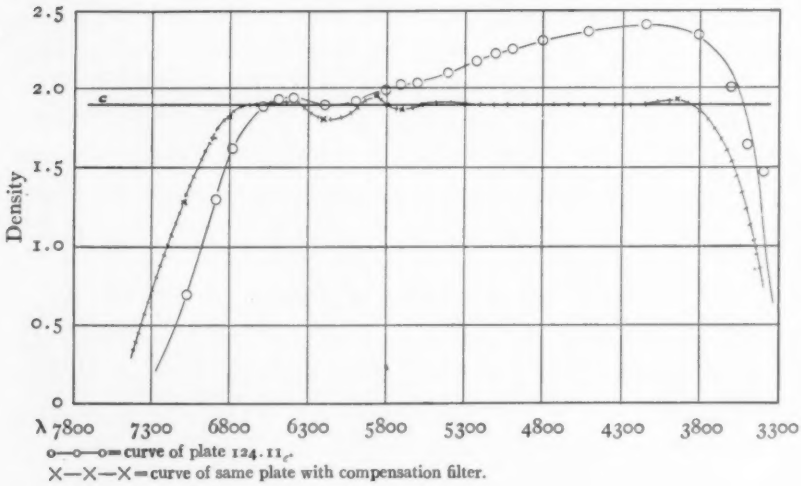


FIG. 10

e = the extinction-coefficient of the filter sought. As c in this instance is represented by a perfectly horizontal line, it is therefore sufficient to accept everything above that line as an absorption record of the filter required, if we now consider c as representing zero density.[1]

In the dye tartrazine we obtain the best agent for the selective absorption of the excessive density in the blue-violet, and ultra-violet as far as λ 3300 which is practically the limit of glass transmission. A spectrum photograph through an adjusted solution of this dye still

[1] In an able paper by André Callier the function and preparation of color-filters is very exhaustively treated, but while the methods and ideas therein expressed are deserving of the highest commendation, yet it must not be lost sight of that all of the curves and measurements are of prismatic spectra.—A. Callier, "Ecrans colorés," *Revue des sciences photographiques*, No. 10, 1906.

leaves much to be desired with reference to the red end, the drop at λ 6200 being quite apparent; this is, however, considerably improved by the introduction to the filter of a very small amount of napthylamine brown.

The best proportionate strength of solution yet arrived at is

	A.	Tartrazine 0.1 gram
		Water 100.0 cc
	B.	Naphthylamine Brown 0.01 gram
		Water 100.0 cc
Compensation filter =	A.	10 cc
		Water 120 cc
	B.	40.0 cc in a thickness of 5 mm

The new curve of sensitiveness is shown in Fig. 10. The introduction of this filter, however, increases the exposure-time by the factor ×2.2. For solar or laboratory absorption spectra this increase is a matter of no consequence. With bright-line emission spectra the use of the filter is unnecessary.

A series of daylight spectra with and without the interposition of the filter is shown in Plate XIV. As increase of exposure tends to a flattening of the curve, the compensated spectra shown are purposely underexposed.

YERKES OBSERVATORY
November 5, 1907

A DETERMINATION OF THE MOON'S LIGHT WITH A SELENIUM PHOTOMETER

By JOEL STEBBINS and F. C. BROWN

Nearly all astronomical photometers are dependent upon the human eye or photographic plate for measures of light-intensity. It is the purpose of the present paper to present the results of experiments with selenium cells in a comparison of the moon's light with that of a standard candle. We have used a similar method for measures of starlight, but the results are reserved for a later publication.

As is well known, the crystalline form of selenium changes its electrical resistance when exposed to light, or under certain circumstances it gives an electromotive force when illuminated. For this latter reason, the crystalline form with electrodes attached was early named "selenium cell."

In 1895 G. M. Minchin[1] succeeded in measuring the current caused by light from bright stars in the focus of a two-foot reflector. The light was received by a layer of selenium immersed in oenanthol. E. Ruhmer[2] has used cells of his own manufacture in observations of solar and lunar eclipses. So far as we know, these are the only applications of selenium to astronomical photometry. A number of attempts have been made by physicists and electricians to perfect a practical form of "selenium photometer," but without success. The maximum sensitiveness of selenium is not in the yellow region of the spectrum, as is the case with the eye, and the effect of temperature changes is another drawback. Experimenters have usually been baffled by unexplained irregularities, some of which originate in the method of making the cells.

The essence of the method of observation used by the writers consists in exposing a cell, usually for 10 seconds, and noting the change of resistance by means of a galvanometer. By taking all precautions

[1] "The Electrical Measurement of Starlight," *Proc. Roy. Soc.*, **58**, 142, 1895.

[2] "Ueber die Wahrnehmung der partiellen Sonnenfinsternis am 31. Oct. 1902 mittelst lichtempfindlicher Selenzelle," *Weltall*, **3**, 63, 1902; "Ueber die Beobachtung der fast totalen Mondfinsternis am 11./12. April 1903 mittels lichtempfindlicher Selenzelle," *ibid.*, **3**, 200, 1903.

suggested by an experience of several months, we have succeeded in obtaining consistent results. The cells used are those on the market by Giltay and by Ruhmer. Two wires are wound close together in a double spiral about a flat insulator, and the spaces on one face are filled with selenium which has been properly sensitized. The exact treatment used by Giltay or Ruhmer is not known to us, and is presumably a trade secret, but the annealing can be accomplished by heating the selenium in place to the melting-point, 217° C., and allowing it to crystallize between 100° and 200°. The constants of the cells are given in the following table:

TABLE I

CONSTANTS OF SELENIUM CELLS

Cell	Dimensions of Sensitive Face	No. of Wires to cm.	Resistance at 20° C.	Change per 1° C.
Giltay 93.....	50×26 mm	17	410,000 ohms	18,000 ohms
Ruhmer 619.....	47×50	20	470,000	27,000
Giltay 94.....	50×26	11	800,000	.....
Remade Giltay.....	50×26	11	3,000,000	20,000

The wires across the sensitive face have the length given by the second dimension, while their number gives the width of the selenium elements. An increase of temperature lowers the resistance of the cells, as shown in the last column. We destroyed the sensitiveness of the fourth cell in some other experiments, and it was reannealed by Mr. Brown. Most of our observations have been taken with Giltay 93, but it was supplemented at times by the Ruhmer cell, and the others were used on only two or three nights.

The arrangement of the apparatus was simple. The cell was connected as one arm of a Wheatstone's bridge, the constant arms being 10 and 1000 ohms. The resistance of the fourth arm was therefore 1/100 that of the cell, and was varied to produce a balance. Current was supplied by two dry batteries giving 2.78 volts. The galvanometer is designated by its makers, Leeds and Northrup, as Type H, and is furnished with flat mirror, view telescope, and a millimeter scale at a distance 0.5 meter from the mirror. As used by us it has a dampening coil and is aperiodic. Under these conditions the galvanometer constant, number of amperes necessary to produce

one millimeter deflection, is 1.6×10^{-8}. The sensibility of the apparatus may be considerably increased by using higher resistances in the constant arms of the bridge, adding more battery, and substituting a more sensitive galvanometer. This would produce larger deflections due to light-action, but would also magnify all disturbing factors. After some months of experiences in trying to obtain steady conditions, we were satisfied to let well enough alone. Great care must be taken in the proper insulation of the apparatus, but as the resistances are high, no trouble was experienced from poor connections.

The standard candle is by Max Kohl and burns amylacetate. The diameter of the round wick is 8 mm, and the height of the flame is regulated to 40 mm. To eliminate air currents, the candle was placed in a blackened box with an opening at one end. To guard against sudden changes of temperature, the cells regularly used were inclosed in boxes covered with asbestos, and the light entered a glass window at one end of each box. Care was taken that the face of the cell was always normal to the incident light. The observers always worked in the same way, Mr. Stebbins making the exposures while Mr. Brown read the galvanometer.

After the electrical resistances were adjusted, the current was left on, and an exposure of the cell to light produced a deflection of the galvanometer. With Giltay 93, a 10-second exposure to the full moon gives about 160 mm. The exposures were made by hand while the observer listened to the one-second beats of a sounder connected with the observatory clock. Experiments in pressing a key under the same conditions show that a 10-second interval may be recorded on a chronograph with a probable error of 0.05 sec. We may assume with confidence that the probable error of an observed deflection, due to exposure-time, does not exceed 1 per cent.

The method of observation was to determine at what distance from the cell the standard candle would produce the same deflection as the light from the moon. Exposures at different distances from cell to candle were taken, and by graphical interpolation the required position was derived. No assumption was made as to the law of variation of the galvanometer deflection with intensity of light.

When possible the cell was first exposed several times to the moon, then followed a series of readings on the candle, and finally another

set on the moon. As the altitude of the moon was changing, the last series never agreed with the first, and it would have been better to "calibrate" with the candle both before and after the lunar observations; but the candle-power of the moon was not known in advance, and the danger from clouds made it imperative to begin with the object in the sky.

In Table II is given a portion of the work of a certain night, taken at random. The first column gives the order, next the Central Standard Time. The distance was measured directly from candle to face of cell, and the distance corresponding to the deflection obtained from the moon is given in parentheses. The mean deflections were plotted, and in this case the curve is nearly a straight line.

TABLE II

OBSERVATIONS WITH GILTAY CELL NO. 93

Friday, June 28, 1907. Resistance 430,000
Moon 48° past full. Temp. 19° C.

Order	Time	Source	Distance	Readings		Deflection	Mean Deflection
			m	mm	mm	mm	mm
1.....	12h 35m	Candle	4.50	7.0	75.0	68.0	....
12.....	15 08	Candle	4.50	25.7	91.3	65.6	66.8
4.....	13 26	Candle	5.00	14.3	72.0	57.7	....
5..	13 38	Candle	5.00	17.9	75.2	57.3	57.5
8.....	14 25	Candle	5.50	20.7	68.9	48.2	....
9.....	14 39	Candle	5.50	21.6	70.4	48.8	48.5
2.....	12 56	Moon	....	4.0	57.0	53.0	....
3.....	13 06	Moon	(5.26)	4.9	57.3	52.4	52.7
6.....	13 50	Moon	....	23.0	87.0	64.0	....
7.....	14 03	Moon	(4.66)	21.3	84.5	63.2	63.6
10.....	14 49	Moon	....	22.5	88.1	65.6	....
11.....	15 00	Moon	(4.51)	24.0	91.4	67.4	66.5

The agreement of the deflections in each pair is very good, and from residuals furnished by these and similar observations may be derived a probable error of approximately 1 per cent. for a single deflection. This is perhaps misleading, and a better test is furnished by the agreement of results on separate nights.

It is necessary to wait for the cell to recover after exposure to a bright light. The first reading was always rejected, and all subsequent exposures were made at nearly the same stage of recovery, as indicated by the galvanometer reading. Near full moon, about five

minutes between exposures were given, while only one minute or less was required for faint lights. In the above sample, the progressive change of the galvanometer zero was due, at least partly, to temperature effect.

The variation of the moon's light with change of phase has not been studied since the time of Zöllner.[1] With a polarizing photometer, he derived the form of the intensity-curve between half and full moon. His results and those of previous visual observers have been summarized by Müller.[2] The observations with selenium cells by the writers during the summer of 1907 give a new determination of the curve of variation with phase, and also the candle-power of the full moon. Before discussing the results, the method of computing the phase, and of applying the necessary corrections will be given.

The phase is counted from full moon, and was computed from the equation

$$\cos \epsilon = -\cos (\lambda - \odot) \cos \beta ,$$

where ϵ is the elongation of the moon from the point opposite the sun, measured on a great circle and considered negative before full moon. The angular phase of the darkened portion of the moon is always within 10′ of the value of ϵ. λ and $\odot$ are the longitudes of the moon and sun respectively, and β is the moon's latitude, all taken from the *American Ephemeris*. The effect of parallax of the moon upon the phase, which never exceeds 1°, may be neglected.

The reduction to mean distance of moon and sun has been accomplished by the following:

$$\text{Reduction to mean distance} = \frac{L_0}{L} = \left[\frac{P_0 \cos (h+P)}{P}\right]^2 R^2 ,$$

where L is the observed and L_0 the corrected brightness of the moon, P_0 the mean equatorial parallax, 57′.0, and P the moon's actual parallax at the altitude h. The factor R^2 reduces to mean distance of sun. A table was prepared giving the logarithm of the term in brackets for each 10° of altitude, and each 1′ of horizontal parallax from 53′ to

[1] "Resultate astrophotometrischer Beobachtungen," *Astronomische Nachrichten*, **66**, 225, 1866.

[2] *Die Photometrie der Gestirne*, Leipzig, 1897, p. 340.

62′. Log R is taken from the *Ephemeris*. In this method we have assumed the earth to be a sphere, and have neglected the moon's varying distance from the sun through the month, which may affect the result by half of one per cent.

The correction for atmospheric absorption may be represented by

$$\phi(z)=0.4a(\sec z-1),$$

where ϕ (z) is the logarithm of the reduction to zenith, and the factor 0.4 is inserted to change from stellar magnitudes to common logarithms. This expression for the absorption has been used for many years at Harvard, where the value of the coefficient a is determined on each night, and is found to average not far from 0.25. For zenith distances less than 75°, $a=0.23$ represents within one per cent. the mean absorption at Potsdam as given by Müller.[1] A rough determination of the absorption is possible from our own observations. On each night, the first and last measures of the moon's light give an equation of the form

$$\log L_2-\log L_1=0.4a(\sec z_1-\sec z_2),$$

where L_1 and L_2 are the candle-powers of the moon at the zenith distances z_1 and z_2. A least-square reduction of the observations on 13 nights, with Giltay 93, gives

$$a=0.50\pm0.26,$$

the large probable error being due in part to the small coefficients which enter into the equations, z_1 never differing by more than 8° from z_2.

This larger value of a produces more accordant results for each night, but the final curve of the moon's light is not improved, and we therefore adopt the absorption correction for mean conditions at Potsdam as given by Müller. This is not much better than a guess at the absorption, as we know that the color-sensibility curves of our cells are probably different from each other, and from that of the eye. Except for the judgment of the observers there was no check upon the variation of the absorption from night to night. No observations were taken through cloud or haze, but we found it extremely difficult to estimate the transparency of the air under different conditions of

[1] *Loc. cit.*, p. 516.

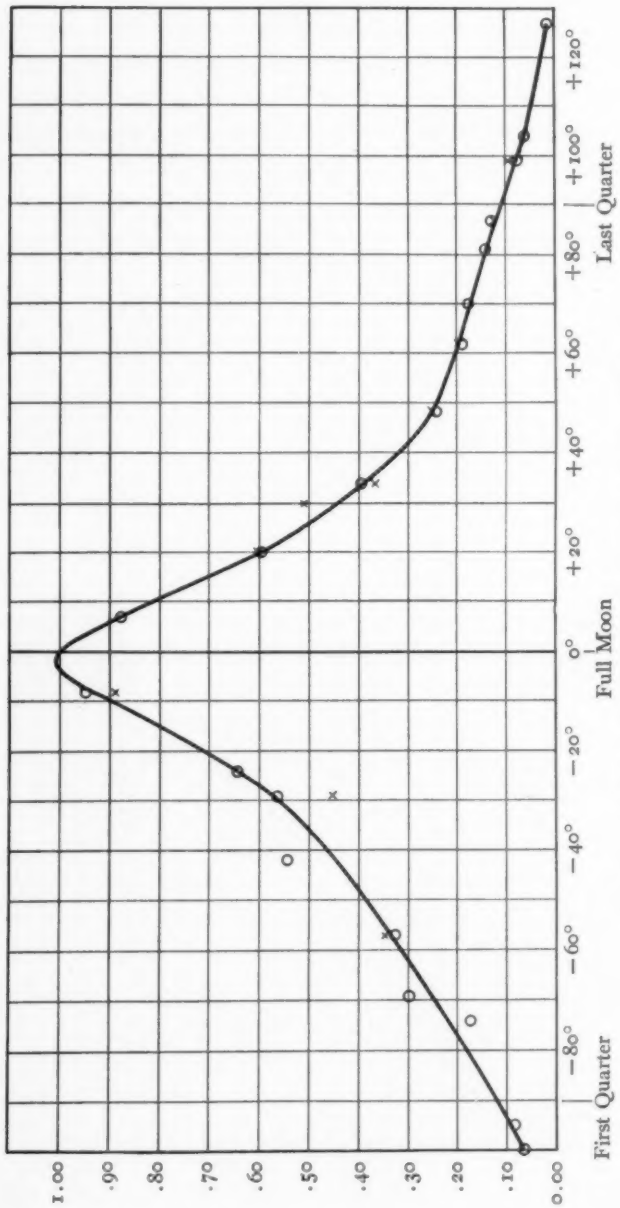


FIG. 1.—Relative Brightness of the Moon at Different Phases

moonlight. For this reason, if for no other, the results of the present paper can be regarded as only preliminary, and we hope to devise an independent method of determining the absorption.

In Table III are given the observations, reduction, and results from different cells, the headings being self-explanatory. The zenith distance was measured at intervals with a small transit, which is easier than to compute it. Its value for the time of each photometric observation was taken from a plotted curve, and is correct within one or two tenths of a degree. The number of exposures refers to the moon, and, since the calibration with the candle was equally important, no attempt has been made to assign different weights to the means. The corrected candle-power is the number corresponding to the sum of the logarithms in the three columns preceding it. In the next to last column is given the brightness in terms of that of the full moon, which is afterward shown to be 0.209 c.-p. for Giltay 93, and 0.0677 for Ruhmer 619.

The results are shown graphically in Fig. 1, where circles represent the observations with Giltay 93, and crosses those with Ruhmer 619, half-weight being assigned to the latter. It will be noticed that there is evidence that the moon is brighter between first quarter and full, than in the corresponding phase after maximum. This came as a complete surprise to the observers, but a glance at the full moon will show that there are more dark areas on the east than the west half, and in particular the third or southwest quadrant is brightest of all. Lord Rosse[1] found that the heat radiation is probably greatest before the full phase, and although Zöllner's curve of light-variation is symmetrical, he rejected one observation which accords with our work. The ends of the curve are necessarily uncertain on account of the low altitudes of the moon in those phases, but the curve can be prolonged to the known value zero at $\pm 180°$. The form near full moon has been drawn as well as possible with the data at hand. Obviously, at opposition the moon may lack 5° of being completely illuminated, and can approach only to about 1°.5 from the center of the earth's shadow without touching the penumbra. The discordant observa-

[1] "On the Radiation of Heat from the Moon, the Law of Its Absorption by Our Atmosphere, and of Its Variation in Amount with Her Phases," *Phil. Trans. Roy. Soc.*, 163, 587, 1873.

TABLE III

Brightness of the Moon with Selenium Cells

Giltay Cell No. 93

Date	G. M. T.	Zenith Distance	No. of Exposures	Deflection	Distance of Candle	Log Candle-Power at 1 Meter	Log Reduction to Zenith, $\phi(z)$	Log Reduction to Mean Distance	Corrected Candle-Power	Mean Candle-Power	Full Moon = 1.000	Phase
1907				mm	m							
June 23....	16^h41^m	59°.1	4	136.0	2.77	9.115	0.087	9.951	0.142	.....	.....	....
23....	17 47	62.7	4	120.0	3.02	9.040	0.110	9.951	0.126	0.134	0.641	−24°
24....	19 39	70.3	1	152.1	2.53	9.194	0.184	9.946	0.211	.....	.....	....
24....	19 54	71.8	1	145.1	2.61	9.167	0.204	9.946	0.208	.....	.....	....
24....	20 20	74.6	1	120.0	3.00	9.046	0.252	9.947	0.176	0.198	0.947	− 8
25....	19 57	67.0	2	153.6	2.63	9.160	0.146	9.944	0.178	.....	.....	....
25....	20 37	70.4	2	149.4	2.68	9.144	0.185	9.945	0.188	0.183	0.876	+ 7
26....	19 44	63.0	2	126.2	3.04	9.034	0.112	9.947	0.124	.....	.....	....
26....	20 32	65.3	2	125.1	3.07	9.026	0.130	9.948	0.127	0.125	0.598	+20
27....	19 30	61.6	3	93.8	3.70	8.864	0.102	9.954	0.0832	0.0832	0.398	+34
28....	19 01	65.2	2½	52.7	5.26	8.558	0.129	9.967	0.0451	.....	.....	....
28....	19 56	60.2	2	63.6	4.66	8.663	0.093	9.965	0.0526	.....	.....	....
28....	20 54	57.0	2	66.5	4.51	8.692	0.076	9.964	0.0540	0.0506	0.242	+48
29....	20 06	60.2	2	48.5	5.56	8.510	0.093	9.978	0.0381	.....	.....	....
29....	20 51	56.0	2	52.4	5.27	8.556	0.071	9.978	0.0403	0.0392	0.188	+62
July 1....	20 28	62.7	2	34.4	6.98	8.312	0.110	0.006	0.0268	.....	.....	....
1....	20 44	60.4	2	36.4	6.78	8.338	0.094	0.006	0.0274	0.0271	0.130	+87
2....	20 30	66.5	2	21.1	9.45	8.049	0.141	0.019	0.0162	.....	.....	....
2....	20 46	63.5	3	21.6	9.20	8.072	0.116	0.019	0.0161	0.0162	0.078	+99
17....	15 21	68.0	2	20.6	9.17	8.075	0.156	0.006	0.0173	.....	.....	....
17....	15 30	69.5	3	20.9	9.09	8.083	0.174	0.006	0.0183	0.0178	0.085	−95
19....	16 06	67.3	4	61.8	4.64	8.667	0.149	9.980	0.0625	0.0625	0.299	−69
20....	14 44	58.0	3	81.0	3.86	8.827	0.081	9.966	0.0748	.....	.....	....
20....	16 17	65.5	5	66.0	4.52	8.690	0.132	9.968	0.0617	0.0682	0.326	−57
21....	17 56	72.6	2	92.7	3.60	8.887	0.217	9.958	0.115	.....	.....	....
21....	18 01	73.5	2	87.5	3.72	8.859	0.232	9.958	0.112	0.114	0.545	−42
22....	15 35	62.6	3	123.8	3.11	9.014	0.109	9.949	0.118	0.118	0.565	−29

TABLE III—*Continued*

Date	G. M. T.	Zenith Distance	No. of Exposures	Deflection	Distance of Candle	Log Candle-Power at 1 Meter	Log Reduction to Zenith, $\phi(z)$	Log Reduction to Mean Distance	Corrected Candle-Power	Mean Candle-Power	Full Moon = 1.000	Phase
1907				mm	m							
July 29....	21h12m	43.5	3	49.6	5.40	8.535	0.031	0.000	0.0368	0.0368	0.176	+70°
30....	20 00	56.0	2	29.2	6.40	8.388	0.071	0.015	0.0298	0.0298	0.143	+81
Aug. 1....	20 36	60.0	5	11.8	10.5	7.958	0.092	0.038	0.0122	.....	.....	....
1....	21 22	51.4	5	14.0	9.20	8.072	0.053	0.035	0.0144	0.0133	0.064	+104
3....	21 07	67.8	5	2.8	21.0	7.356	0.154	0.053	0.0037	.....	.....	....
3....	21 15	66.5	5	2.1	23.2	7.269	0.141	0.052	0.0029	.....	.....	....
3....	21 31	63.4	3	2.5	22.0	7.315	0.115	0.052	0.0030	0.0032	0.015	+127
15....	14 48	73.3	4	7.8	11.1	7.909	0.228	9.994	0.0135	0.0135	0.065	−100
17....	15 14	68.5	4	39.1	5.85	8.466	0.162	9.972	0.0398	.....	.....	....
17....	15 45	72.6	3	30.8	6.95	8.316	0.217	9.973	0.0321	0.0360	0.172	− 74
Ruhmer Cell No. 619												
June 24....	18 38	64.5	4	21.4	4.48	8.697	0.123	9.945	0.0582	.....	.....	....
24....	19 24	68.9	3	20.6	4.56	8.682	0.166	9.946	0.0622	0.0602	0.889	− 8
26....	20 22	64.7	2	16.2	5.38	8.538	0.125	9.948	0.0408	0.0408	0.603	+20
27....	19 44	61.0	2	21.4	6.75	8.341	0.098	9.954	0.0247	0.0247	0.365	+34
28....	18 47	66.7	2	10.6	8.73	8.118	0.143	9.967	0.0169	.....	.....	....
28....	19 11	64.2	1	11.8	8.45	8.146	0.121	9.966	0.0171	.....	.....	....
28....	19 38	61.8	2	12.4	8.35	8.157	0.104	9.966	0.0169	.....	.....	....
28....	20 32	58.0	2	13.2	8.17	8.176	0.081	9.965	0.0167	0.0169	0.250	+48
29....	20 58	55.3	3	9.6	9.15	8.077	0.068	9.978	0.0133	0.0133	0.196	+62
July 1....	21 18	55.3	4	6.4	12.0	7.842	0.068	0.007	0.0083	0.0083	0.123	+87
2....	21 02	60.7	3	3.8	14.0	7.708	0.096	0.018	0.0066	0.0066	0.097	+99
20....	14 59	58.6	2	12.5	6.47	8.378	0.084	9.966	0.0268	.....	.....	....
20....	15 59	63.7	4	8.5	7.80	8.216	0.117	9.967	0.0200	0.0234	0.346	−57
22....	15 44	62.5	2	15.4	6.15	8.422	0.108	9.949	0.0301	.....	.....	....
22....	17 28	66.2	2	15.0	6.22	8.412	0.138	9.949	0.0316	0.0308	0.455	−29
26....	19 47	54.5	3	23.2	5.53	8.515	0.065	9.959	0.0346	0.0346	0.511	+30

TABLE III—*Continued*

Giltay Cell No. 94

Date	G. M. T.	Zenith Distance	No. of Exposures	Deflection	Distance of Candle	Log Candle-Power at 1 Meter	Log Reduction to Zenith, $\phi(z)$	Log Reduction to Mean Distance	Corrected Candle-Power	Mean Candle-Power	Full Moon = 1.000	Phase
				mm	m							
July 22....	18h00m	68.6	3	55.3	2.96	9.057	0.348	9.950	0.226	0.226	.....	− 29°
26....	20 16	54.5	2	69.0	2.59	9.173	0.144	9.959	0.189	.....	.....	....
26....	20 59	55.5	2	57.8	2.92	9.069	0.153	9.959	0.152	0.170	.....	+ 30
Aug. 1....	21 33	49.5	5	9.8	7.60	8.238	0.108	0.034	0.0240	0.0240	.....	+104
					Remade Giltay Cell							
July 20....	16 54	70.0	3	3.6	5.40	8.535	0.385	9.970	0.0776	.....	.....	....
20....	17 05	71.5	3	3.2	5.90	8.458	0.430	9.970	0.0721	0.0748	.....	−57
22....	17 38	66.7	4	7.4	3.78	8.845	0.306	9.949	0.126	0.126	.....	−29

tions at phases $-42°$ and $-74°$ were taken at zenith distances greater than 70°, and the uncertainty of the absorption must be the cause of these large deviations. The general agreement of the plotted points with the curve is perhaps an indication of the reliability of our results, and with uniform conditions the accordance of measures with selenium is at least equal to that of visual observations.

One of the interesting facts which may be seen in the curve is that the full moon is approximately nine times as bright as the half moon. The flashing out of the full moon has long been ascribed to the rough character of its surface, and it is evident that any mathematical theory of the light-variation will be complicated by the irregularity of the lunar features. The expression which Zöllner derived for the variation of the moon's light has been shown to be a mere interpolation formula.

Inasmuch as the selenium photometer is still in the experimental stage, it does not seem worth while to compare at length our work with that of visual observers. Table IV gives the variation derived from our curve, and a comparison with that of Zöllner, where his

TABLE IV

BRIGHTNESS OF THE MOON AT DIFFERENT PHASES

Phase	Observed	Zöllner	O.−Z.
−100°	0.06	....	.....
− 90	.12	....	.....
− 80	.18	....	.....
− 70	.25	0.17	+0.08
− 60	.32	.24	+ .08
− 50	.38	.33	+ .05
− 40	.46	.44	+ .02
− 30	.56	.56	.00
− 20	.71	.70	+ .01
− 10	.90	.85	+ .05
0	1.00	1.00	.....
+ 10	0.81	0.85	− .04
+ 20	.60	.70	− .10
+ 30	.44	.56	− .12
+ 40	.32	.44	− .12
+ 50	.24	.33	− .09
+ 60	.20	.24	− .04
+ 70	.17	.17	.00
+ 80	.14	....	.....
+ 90	.11	....	.....
+100	.07	....	.....
+110	.05	....	.....
+120	.03	....	.....

values are as given by Müller, and the logarithms are reduced to numbers to correspond with our adopted values.

To determine the brightness of the full moon, the corrected candle-powers in Table III were plotted, giving a curve similar to Fig. 1. From the observations with Giltay 93, we derive 0.209 c.-p. for the full phase. Due to what must be a different color-sensitiveness, the Ruhmer cell invariably gives the candle-power of the moon about one-third as great as is found with Giltay 93. The ratios on different nights are as follows:

June 24	0.304
June 26	0.326
June 27	0.297
June 28	0.334
June 29	0.339
July 1	0.306
July 2	0.407
July 20	0.343
July 22	0.261
Mean	0.324

Multiplying the result from Giltay 93 by 0.324, the brightness of the full moon given by Ruhmer 619 is 0.0677 c.-p., and in the same way have been derived the results for the other cells. The adopted values, rounded off to two places, are as follows:

TABLE V

CANDLE-POWER OF FULL MOON

Cell	Candle-Power	Thickness of Glass
Giltay 93	0.21	1.1 mm + 3.3 mm
Ruhmer 619	0.07	2.6 + mica
Giltay 94	0.37	1.1
Remade Giltay	0.23	1.1

The thicknesses of the protecting pieces of glass or mica are inserted to show that no appreciable effect is due to them. The results of visual observers vary from 0.16 to 0.30 c.-p., and Müller[1] adopted a mean value of 0.23 c.-p. This happens to agree closely with the mean of our four cells, but the discrepancies above shown are inherent in

[1] *Loc. cit.*, p. 338.

the nature of the cells, and are not due to accidental errors of observation. We propose to determine the color-curve of each cell, but this will require some time, and the phase-variation of the moon's light is presumably about the same for all colors. It should be noted that our values include the effect of the bright background of the sky, which from some rough measures we estimate to be of the order of 5 per cent. of the total.

It was planned to observe the partial lunar eclipse of July 24, 1907, but unfortunately the night was cloudy. At intervals the moon was seen through clear spaces from 5° to 20° wide, and a few exposures were made. Great care was taken that no light cloud interfered. The deflections obtained were as follows:

TABLE VI

OBSERVATIONS WITH GILTAY CELL NO. 93 DURING PARTIAL LUNAR ECLIPSE, JULY 24, 1907

G. M. T.	Deflection
$16^h\ 02^m$	49.3 mm
16 04	43.7
16 06.5	43.1
16 29	36.4
16 31	36.6
16 33.5	37.6
16 35	37.9
16 36	38.3
17 07	87.1
17 07.5	87.3

The above values were plotted, and neglecting the effect of differential absorption due to the moon's changing altitude, the instant of least light, derived from times of equal deflection, was found to be $16^h\ 23^m$. According to the *Ephemeris*, the middle of the eclipse came at $16^h\ 22^m.4$, but this close agreement is partly accidental under the circumstances.

The original article by Ruhmer is not available, but from references it seems that his cell was continually exposed during the eclipse. Our experience with selenium has been that the best results are secured with short exposures.

SUMMARY

1. It has been shown that selenium cells can be used for accurate photometric measures of objects about as bright as the moon, and the results are at least as accordant as those from visual observations.

2. From a comparison of the moon with a standard candle, has been derived the variation of moonlight with phase. The full moon gives us approximately nine times as much light as the half moon, and the gibbous disk is brighter before than after full moon.

3. The candle-power of the full moon, as measured with selenium cells, is of the same order as that obtained by visual observers; but different cells give discordant values, which probably depend upon the different color-sensibility of the cells.

4. With the aid of a selenium cell, the central phase of a lunar eclipse was determined within one minute of the predicted time.

In conclusion we beg to acknowledge our indebtedness to Professor A. P. Carman of this university, who placed the facilities of the physical laboratory and shop at our disposal.

UNIVERSITY OF ILLINOIS OBSERVATORY
September 1907

ON THE SPECTRA OF TWO METEORS

By S. BLAJKO

In 1904 I constructed a prismatic camera from a Voigtländer euryscope of aperture 50 mm and focal length 300 mm, and a prism of crown glass with a refracting angle of 45°. During the exposure of the first plate with this instrument, on May 11, 1904, a bright meteor appeared in the field of view of the camera and its spectrum was obtained. The driving clock had been regulated to sidereal time, and the stellar spectra therefore appeared as fine narrow streaks parallel to the hour circle passing through the center of the plate. The lines of hydrogen may readily be seen as interruptions in the streaks in the case of stars of the first spectral type. The co-ordinates of the center of the plate are: $\alpha = 0^h\,40^m$, $\delta = +80°.0$, referred to the equinox of 1855; to which all other right ascensions and declinations in this paper are referred, as the photographs were compared with the charts of the *B.D.*

The spectrum of the meteor consists of fine lines of different degrees of brightness which lie parallel to each other from one edge of the plate ($\alpha = 21^h\,52^m$, $\delta = +78°.0$) to the other ($\alpha = 4^h\,50^m$, $\delta = +80°.5$), and are curved on account of the action of the prism, their average inclination to the direction of the stellar spectra being about 78°. The lines are much broadened from the position, $\alpha = 4^h\,20^m$, $\delta = +81°.2$. A sudden increase in brightness obviously occurred at this moment; there was no noticeable increase in the number of spectral lines, merely the brightness increased. No trace of a continuous spectrum can be seen.

The apparent path of this meteor among the stars was obtained with the photographic camera (an Aplanat of Steinheil of free aperture 97 mm and focal length 640 mm) which has been employed here in recent years for the systematic photography of the heavens. It was this time directed intentionally toward about the same region of the sky as was the prismatic camera. The track of the meteor, which is almost a straight line, brightens from one edge of the plate ($\alpha = 20^h\,46^m$, $\delta = +67°.0$) to the other ($\alpha = 0^h\,55^m$, $\delta = +83°.0$). The co-ordinates of the center of the plate are $\alpha = 20^h\,12^m$, $\delta = +77°.3$.

By accident I saw this meteor at the end of its appearance; it was of about the first magnitude or somewhat brighter, and of a yellow color; the train it left behind was about 25° long and was visible for about three seconds, at $12^h\ 36^m$, Moscow Mean Time.

Encouraged by this fortunate chance, I directed both instruments toward the radiant of the Perseids on August 12, 1904. During the exposure at $13^h\ 6^m$, Moscow Mean Time, there appeared a bright Perseid which was observed by Mr. Taschnow and myself. During the latter half of its path, after its brightness had undergone a sudden increase, it was nearly of the first magnitude and was of a pure-green color. Its spectrum and its path among the stars were photographed, the position of the center of the two plates being: $\alpha = 3^h\ 17^m\ 21^s$, $\delta = +59°\ 25'.9$. The track of the meteor begins on the star plate at $\alpha = +2^h\ 23^m 48^s$, $\delta = +59°\ 0'.0$; its brightness increases a little up to the point at $\alpha = 2^h\ 18^m\ 17^s$, $\delta = +59°\ 4'.6$, then decreases slightly to the point at $\alpha = 2^h\ 17^m\ 0^s$, $\delta = +59°\ 5'.5$. A sudden and marked increase in brightness is noticed at $\alpha = 2^h\ 14^m\ 22^s$, $\delta = +59°\ 7'.5$, which is then retained almost to the end ($\alpha = 2^h\ 8^m\ 58^s$, $\delta = +59°\ 10'.2$). Only a single line is seen in the spectrum up to the position of the increase in brightness, but from here onward other faint lines appear, no trace of a continuous spectrum being noted, however. The inclination of the track of the meteor to the direction of the stellar spectra is about 75°.

The emission spectra of the two meteors are entirely different from each other.

A procedure entirely rigorous in principle can be employed for determining the wave-lengths of these spectral lines, inasmuch as in both cases the path of each meteor among the stars is known as well as its spectrum. The simple idea on which the process must be based is the following: We must determine a relation between the co-ordinates of suitable stars on the stellar plate and the co-ordinates of the position of a definite spectral line, for instance $H\gamma$, in the spectra of the same star on the spectral plate. From the co-ordinates of the separate points of the track of the meteor on the stellar plate, the co-ordinates of the corresponding points on the spectral plate may be derived and consequently the position of the wave-length in question, i. e., λ 4340.5, can be determined in the spectrum of the

meteor. If the same procedure is carried out for two other wave-lengths, we shall get the positions of three lines of known wave-length in the spectrum of the meteor, whence by means of Hartmann's formula we may derive the wave-lengths of the other lines present in the spectrum.

In the practical execution of this idea, however, we encounter several difficulties. In the first place, the spectral image of the sky is largely distorted by the action of the prism; secondly, an error occurs in the determination of the path of the meteor among the stars on the stellar plate from the fact that the distribution of brightness is not the same in the spectrum of the meteor as in the spectra of the stars, whence the chromatic differences of focus of the objective come in evidence, particularly when the track of the meteor is not very close to the optical axis, as is here the case. The amount of the second error cannot be computed without a knowledge of the spectrum of the meteor and without precise data as to the design of the objective. The effect of the prism involves an inconvenient computation and is not very important without a knowledge of the second error. I therefore decided not to take these errors into account in advance, and I treated the plates in the following manner.

The Troughton measuring machine, with which all the measurements were made, has two scales, A and B, perpendicular to each other. The spectral plate was so oriented under the machine that the direction of the stellar spectra was parallel to scale A, and then, on the one hand, the readings A were made for all lines visible in the spectrum of the meteor for different values of B; on the other hand, the readings A and B were made for the hydrogen lines in the spectra of those stars which fell alongside the spectrum of the meteor and not too far from it. These showed that the dispersion is practically the same at different points of the spectrum of the meteor. Then the relation between the co-ordinates A and B of the different points of the brightest line (in the second case the longest line) would be expressed by an equation of the form:

$$A' = A_0 + \alpha(B - B_0) + \beta(B - B_0)^2 .$$

The co-ordinates computed by this formula pertaining to the different values of B, are probably more accurate than those read

off directly in the measuring machine. Corresponding values of A' were computed for the co-ordinates B, for which the co-ordinates A of the fainter spectral lines were found by measurement; the direct values A of the fainter lines were then compared with these computed values A', and from the differences thus obtained mean values were formed for each line, and thus the definitive distances of all the spectral lines from the brightest line were obtained.

The co-ordinates of the hydrogen lines of the stellar spectra were treated in a similar manner. The reduction of the A co-ordinates of all the hydrogen lines for each star to a selected star was deduced by forming the mean of the separate differences of the separate lines of the two stars; after reducing all the stellar spectra measured to the spectrum of the selected star, the mean values were taken from the co-ordinates obtained for each line, and thus definitive co-ordinates for the hydrogen lines were obtained for this star; by applying the reductions mentioned to these co-ordinates, definitive A co-ordinates were formed for the hydrogen lines of the other stars.

The stellar plate with the track of the meteor was oriented in the measuring machine as nearly as possible in the same way as the spectral plate had been, and the A and B co-ordinates were obtained for the same stars and for a number of points in the meteor's track; the co-ordinates of the track of the meteor were adjusted by means of the formula:

$$A' = A_0 + \alpha'(B - B_0) + \beta'(B - B_0)^2 .$$

The ratio of the scales of the two plates was computed from the differences of the co-ordinates of the stars on the stellar and spectral plate (particularly the B co-ordinates); that is, the coefficient was obtained by which the differences of co-ordinates of the one plate must be multiplied in order to obtain the corresponding differences of co-ordinates of the other plate.

Finally the difference of the A co-ordinate of the star and the A' co-ordinate of the point in the meteor track for the same B co-ordinate at which it was measured in the case of the stars, was determined for each star; it was then multiplied with the above-mentioned coefficient and added to the definitive A co-ordinates of the hydrogen lines of this star on the spectral plate. In this way was accomplished what we may call the transfer of the hydrogen spectrum on to the

spectrum of the meteor. I formed the mean of all *A* differences between a hydrogen line and the brightest lines of the meteor spectrum (in the second case the longest line), and the distribution of the hydrogen wave-lengths thus obtained among the spectral lines of the meteor was made the basis of further computations.

In order to increase the strength of the fainter lines of the meteor spectrum and to diminish the effect of the errors of setting and the errors of the machine, I made an enlarged positive from the original negative of the meteor spectrum, and from this a second negative by contact. It was on this negative that I made the measurements.

From this description of the method employed it may be seen that the principal error affecting the determination of wave-lengths depends on the fact that the transfer of the hydrogen spectrum to the spectrum of the meteor cannot be perfect. In order to improve the wave-lengths of the meteor spectrum thus found, the spectrum must, so to speak, be displaced on its scale; or what is the same thing, the corrections must be added to the separate wave-lengths, which are inversely proportional to the dispersion at the positions in the spectrum in question. The value of the corresponding proportional factor, however, cannot be determined until we are able to identify a number of lines of the meteor spectrum with the spectral lines of some terrestrial element.

METEOR OF MAY 11, 1904

TABLE I

Inches	μμ	μμ		μμ	μμ	
2.24788	357.82		218	−0.52	357.30	3 weak
2.27710	364.40		233	−0.55	363.85	4
2.31988	374.90		258	−0.62	374.28	4 double
Hθ 2.33839	379.80					
Hη 2.35215	383.59					
2.35437	384.22		282	−0.67	383.55	3
2.36201	386.40		288	−0.69	385.71	3
Hζ 2.37040	388.84					
2.38781	394.08	−0.70	308	−0.73	393.35	10
He 2.39730	397.05					
2.39915	397.63	−0.77	318	−0.76	396.87	5
2.42175	405.06		339	−0.81	404.25	2 double
Hδ 2.43652	410.18					
2.44801	414.31		366	−0.87	413.44	1 double
2.47262	423.66	−0.96	394	−0.94	422.72	1 sharp
Hγ 2.49796	434.07					

The table contains in the first column the A co-ordinates in English inches of the lines of the meteor spectrum and of the hydrogen lines. The last decimals are merely the results of computation. The last column gives relative brightness and remarks as to the appearance of the lines. In deriving the Hartmann formula I assumed the following wave-lengths for the hydrogen lines, after Evershed:[1]

$H\theta - 379.80$,	$H\eta - 383.55$,	$H\zeta - 388.92$,
379.80	383.59	388.84
$H\epsilon - 397.00$,	$H\delta - 410.20$,	$H\gamma - 434.05$
397.05	410.18	434.06.

The second line of values was obtained by the formula:

$$\lambda = 167.48 + \frac{[2.22130]}{3.12238 - A}.$$

The corresponding wave-lengths of the spectrum of the meteor are given in the second column of the table.

There can be scarcely any doubt that the two brightest lines are the calcium lines H and K of the solar spectrum, for the small and surely trustworthy corrections of -0.77 and $-0.70\ \mu\mu$ suffice for reducing the computed wave-lengths to the wave-lengths of those lines (396.86, 393.38). The line 423.66 similarly belongs to the calcium spectrum; the relative intensity of this line as compared with H and K is known to be very dependent on the conditions under which the calcium vapor is brought to luminosity; the computed wave-length required a correction of $-0.97\ \mu\mu$.

The fourth column gives $\frac{d\lambda}{dA}$. From the corrections of the three calcium lines the displacement of the meteor spectrum on its scale comes out -0.00238 inches (mean of -0.00227, -0.00242, -0.00246); the corresponding corrections of the remaining wave-lengths are given in the fifth column, and definitive wave-lengths in the sixth column.

As to the identification of the remaining lines, the means at my disposal, consisting of the *Atlas der Emissionsspectren* by A. Hagenbach and H. Konen, and the *Wellenlängen Tabellen* by F. Exner and E. Haschek, enabled me to determine the following points:

[1] *Memoirs of the Royal Astronomical Society*, **54**, Appendix V.

The wave-length 383.55 corresponds to the *Mg* lines 382.95, 383.25, 383.84, which are the brightest magnesium lines in the portion of spectrum photographed.

λ 404.25 $\mu\mu$ represents the double potassium line 404.43 and 404.75, which is similarly the brightest *K* line in this part of the spectrum.

METEOR OF AUGUST 12, 1904

The spectrum of this meteor lies farther from the center of the plate than is the case of the earlier meteor, so that the measurements, particularly those of the hydrogen lines in the stellar spectra, are more uncertain.

TABLE II

Inches	$\mu\mu$	$\mu\mu$	$\mu\mu$	$\mu\mu$	
1.98752	376.11	+1.48	+1.37	377.48	2
2.00553	377.69		+1.34	379.03	2
2.02020	378.99		+1.30	380.29	2
2.03968	380.74	+1.24	+1.27	382.01	1
$H\eta$ 2.06923	383.46				
2.07550	384.04		+1.21	385.25	1 a line?
2.11644	387.91	+0.97	+1.15	389.06	10 long
$H\zeta$ 2.12810	389.08				
2.14136	390.39		+1.12	391.51	2 double?
2.16531	392.79		+1.08	393.87	1
2.19044	395.37	+1.12	+1.06	396.43	1 a line?
$H\epsilon$ 2.20729	397.12				
2.21754	398.22		+1.04	399.26	5
2.24963	401.68	+0.95	+1.02	402.70	3
2.28516	405.64		+1.01	406.65	1 a line?
$H\delta$ 2.32431	410.16				
2.33170	411.03	+1.07	+1.00	412.03	1 diffuse
$H\gamma$ 2.50794	433.89				

The first column again gives the *A* co-ordinates, and the last column gives the relative brightness and remarks. The second contains the wave-lengths computed by the formula

$$\lambda = 168.44 + \frac{[2.69698]}{4.37865 - A}.$$

We see that the hydrogen wave-lengths are represented less satisfactorily than in the first case, whence we may expect that the corrections of the wave-lengths in the spectrum of the meteor will be larger than for the first meteor. The comparison of the meteor

spectrum with the spectra of terrestrial elements indicated that the wave-lengths

380.74, 387.91, 395.37, 401.68, 411.03

lie close to the positions in the spectrum of the brightest lines of helium and also so nearly match their relative brightness that there can be no doubt of the presence of this element in the meteor. In the *Astrophysical Journal* (**3**, 9, 10, 1896) Messrs. Runge and Paschen give for these lines the following wave-lengths and relative intensities:

381.98 (4), 388.88 (10), 396.49 (4), 402.63 (5), 412.10 (3).

The corrections required for the computed wave-lengths are given in the third column.

The pure-green color of the meteor doubtless indicates that the wave-length 376.11 corresponds to the thallium line at 377.59 which is the brightest in this portion of the spectrum. The corrections found for six wave-lengths ought to be treated in the same way as for the meteor of May 11, but they show again that the measurements, particularly in the hydrogen lines in the stellar spectra (which determine the scale of the spectrum), are here insufficiently precise, inasmuch as the progression of the corrections is reversed from that which corresponds to the displacement of the spectrum on its scale. I therefore drew an interpolation curve, based upon the corrections given, and took from it the corrections to the computed wave-lengths; these corrections are given in the fourth column, while the fifth contains the definitive wave-lengths. I was unable to certainly identify any other line with any line of a terrestrial element.

OBSERVATORY, MOSCOW
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ON THE QUANTITATIVE SPECTRA OF CERTAIN ELEMENTS[1]

By JAMES H. POLLOK and A. G. G. LEONARD

INTRODUCTION

The following quantitative spectra of iron, aluminium, chromium, silicon, zinc, manganese, nickel, and cobalt, are, with slight modifications, taken after the manner devised by Professor W. N. Hartley, as published in the *Philosophical Transactions of the Royal Society* in 1884, **175**, 49–62, 325–342.

For analytical purposes a knowledge of the residuary lines of spectra is of the greatest assistance, as on diluting a solution of a salt, the lines of the spark-spectrum disappear so rapidly, that with 0.1 per cent. solutions, the spectrum is difficult to identify by reference to an index where all the lines of the element are carefully recorded, especially as the last lines that disappear are not necessarily the most intense. On a plate giving the spark-spectrum of some chloride of beryllium, let us say, one might very well have a few foreign lines closely agreeing with lines of iron, manganese, or titanium, and without very exact measurement, it might be impossible to decide to which they belonged; but on the other hand, if we knew that these lines were the residuary lines of titanium, and that the residuary lines of iron and manganese were quite different, we should know definitely that a trace of titanium was present, and not iron or manganese. Again, if we know that the residuary lines of an element are absent, we know at once that the element is absent, so that it is only necessary to look for the residuary lines. Hartley investigated the dilution spectra of a large number of elements; but with the exception of aluminium, silicon, and zinc, the above are not among them, and as the authors are engaged in an investigation of the methods of separating the elements of the cerium and yttrium groups, they find that a knowledge of the residuary lines of all the common elements of the ammonia and ammonium sulphide groups is necessary. Gold electrodes have been substituted for graphite to bring

[1] Extract from *Scientific Proceedings of the Royal Dublin Society*, 11, Nos. 17 and 18, July 1907.

the spectra into uniformity with other work by the authors, and in particular to make them readily comparable with the general index of spectra published by one of the authors in the *Proceedings* of this society. On comparison of the dilution spectra of zinc and silicon with those of Hartley, it would seem that gold electrodes are not so sensitive as graphite. The results are otherwise substantially the same, a few more lines having been observed with a 1 per cent. solution of zinc, and all the lines disappear more rapidly; the last lines to disappear on dilution are identical with those observed by Hartley. That graphite should be more delicate than gold appears very natural, as the graphite tends to absorb the solution-sparks over a larger surface, and hence yields more vapor of the element under examination; but for all ordinary analytical purposes, gold is more convenient.

The work was done with a one-prism quartz spectrograph, by Hilger, using the spark produced by a Ruhmkorff's coil and condenser, with a Hemsalech self-induction coil placed in the circuit for the removal of air-lines. The plates were "Rainbow Fast," made by the Warwick Photo Co., and in every case the exposure was 1 minute; this photographed clearly from λ 4792.8 to λ 2544 on one plate. To go farther down in the ultra-violet, it would be necessary to readjust the instrument and take another set of photographs.

The general method of procedure was to make a strong or saturated solution of the chloride of the element under consideration; also solutions containing one gram of the element in every 100, 1000, 10,000, 100,000 parts of solution. A photograph was taken of the gold electrodes with a long slit; the slit was then shortened and the metal sparked, thus giving the spectrum of gold with long lines, and the spectrum of the metal with short lines. The process was then reversed, the metal taken long, and the gold short, so that any lines coincident with gold lines might be seen. A photograph was taken then with both the strong solution and gold electrodes long, and the metals short, to show any lines developed by the metals, but not by their solutions. Then in every case the last four spectra taken gave the gold electrodes long, with short lines between, of the spark spectra of solutions containing 1 per cent., 0.1 per cent., 0.01 per cent., 0.001 per cent. of the element under examination.

To distinguish briefly between the different phases of the lines with diminishing concentration, use has been made of some of the letters of the Greek alphabet, with the following meanings:

τ = seen with the metal, but not with strong solutions.
σ = " " strong solutions, but not with 1% solutions.
ϕ = " " 1% " " " " 0.1% "
χ = " " 0.1% " " " " 0.01% "
ψ = " " 0.01% " " " " 0.001% "
ω = " " 0.001% "

No new measurements were attempted, the lines being identified by means of a finely graduated ivory scale, and the corresponding published lines tabulated. In the case of manganese, however, one of the residuary lines, λ 2594.0, was not found in the tables at our disposal, and our own measurement is given.

In the case of cobalt the solution was not diluted so abruptly, and this shows the gradual extinction of the lines with diminishing concentration better than the others; but as the whole object was to find the residuary lines, one passes directly from a saturated solution to a solution containing only 1 per cent. of the element under examination, and then dilutes until the lines entirely disappear. In the case of chromium, silicon, manganese, and zinc, all the dilutions are not given in the plates,[1] as lines that can still be seen on the negatives cannot be seen in the reproductions at all, as will be obvious by comparing the tables with the plates. Even with 1 per cent. solutions, the lines do not come out by any means strongly with one minute's exposure, and with 0.1 per cent. they are always very faint, and very few substances give lines that will show at all with 0.001 per cent.

GOLD ELECTRODES

To facilitate the identification of the lines, some of the strong gold lines have been numbered, from 10 to 25, and their wavelengths are given in the Table I; and in the subsequent tables these numbers are inserted in their proper place. Thus in the case of chromium, we see from the table that the first triplet of persistency ψ lies between 11 and 12, and we know where to look for it on the plate.

[1] The author's plates are omitted here.

TABLE I

NUMBERED GOLD LINES

No.	Wave-Length	No.	Wave-Length
9.....	4792.8	18.....	3029.3
10.....	4488.4	19.....	2913.6
11.....	4315.4	20.....	2825.6
12.....	4065.2	21.....	2748.3
13.....	3898.0	22.....	2676.1
14.....	3586.5	23.....	2641.6
15.....	3383.0	24.....	2590.2
16.....	3280.8	25.....	2544.3
17.....	3122.9		

IRON

The progressive disappearance of the lines of dilute solutions is given in the following table; but there are so many ϕ lines that it

TABLE II

QUANTITATIVE SPECTRUM OF IRON CHLORIDE

Wave-length	Intensity and Persistency	Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
10		3618.9	10 ϕ	2692.7	6 ϕ
4415.3	8 σ	3610.3	4 ϕ	22	
4404.9	10 σ	3609.0	9 ϕ	2684.8	6 ϕ
4383.7	10 ϕ	14		2666.7	7 ϕ
4325.9	10 σ	3581.3	10 χ	2664.7	7 ϕ
11		3570.3	8 χ	2631.4	4 ψ
4308.0	10 σ	3565.5	8 χ	2628.4	8 ψ
4271.9	10 σ	3490.7	6 ϕ	2625.8	7 ψ
4260.7	10 σ	3475.6	7 χ	2621.7	6 χ
4250.9	8 σ	3466.0	7 χ	2617.7	7 χ
4071.9	10 σ	3441.1	7 χ	2613.9	9 χ
12		15–18		2612.0	9 χ
4046.0	10 σ	3021.2	2 ψ	2607.2	9 χ
4005.3	8 σ	3020.8	2 ψ	2599.5	10 ψ
13		2973.4	2 χ	2598.5	9 ψ
3860.1	9 σ	2970.2	2 χ	2586.0	8 χ
3828.0	9 σ	2967.0	2 χ	2567.0	4 χ
3816.0	9 σ	2965.4	1 χ	2562.0	6 ψ
3767.3	7 ϕ	19–20		2549.7	4 χ
3758.4	8 ϕ	2783.8	7 ϕ	25	
3749.6	10 ϕ	2779.3	5 ϕ	2539.0	5 χ
3745.7	7 ϕ	2767.6	7 ψ	2533.9	7 χ
3737.3	8 ψ	2755.8	10 ψ	2529.6	6 ϕ
3735.0	10 ψ	2747.1	7 ϕ	2526.3	6 ϕ
3722.7	6 ψ	2743.2	8 χ	2525.5	7 ϕ
3720.1	8 ψ	21		2522.9	6 χ
3687.6	6 ϕ	2739.6	10 ψ	2511.8	7 χ
3648.0	9 ϕ	2727.6	8 χ		
3631.6	10 ϕ	2714.5	7 χ		

was not thought necessary to record more than the strongest. Some of the lines that show well with a strong solution, but are not seen with dilute solutions, are marked σ.

ALUMINIUM

There is a strong aluminium line at λ 3587.0, practically coincident with gold line No. 14 (λ 3586.5), and in consequence it cannot be followed in the dilution spectra. Quite a number of lines show strongly with the metal, but only very faintly, or not at all, with solutions. Of those the following belong to aluminium:

4663.1	10 τ	3064.4	8 τ
4530.5	6 τ	3057.3	8 τ
4511.9	6 τ	3054.8	8 τ
4479.4	6 τ	3050.2	8 τ
3066.3	8 τ		

The rest between gold lines 22 and 24 belong to iron, and come from the small traces of iron in metallic aluminium, and they correspond with the most persistent lines of the iron solutions.

TABLE III

QUANTITATIVE SPECTRUM OF ALUMINIUM CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
3961.7	9 ω	2816.4	10 χ
3944.2	9 ω	21–22	
13		2660.5	5 ϕ
3587.0	10 ϕ	2652.6	5 ϕ
14–17		23–24	
3092.8	9 ψ	2575.5	7 ϕ
3082.3	9 ψ	2568.1	7 ϕ
18–20		25	

CHROMIUM

We photographed the lines of an alloy of 50 per cent. chromium and 50 per cent. iron short, with gold and iron lines long, the iron lines of the long spectrum thus canceling the iron lines in the short, and showing only the chromium lines short. This plan was adopted owing to the difficulty of procuring or making chromium free of iron.

TABLE IV

QUANTITATIVE SPECTRUM OF CHROMIUM CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
11		2988.8	8 ϕ
4289.9	10 ψ	2980.9	8 ϕ
4274.9	10 ψ	2971.9	8 ϕ
4254.5	10 ψ	2953.4	8 ϕ
12–13		19	
3605.5	10 χ	2843.3	10 ψ
3593.6	10 χ	2835.2	10 ψ
14		2830.5	10 ψ
3578.8	10 χ	20	
3430.5	10 ϕ	2766.6	8 ϕ
3422.9	10 ϕ	2762.7	8 ϕ
3421.4	10 ϕ	21	
3408.9	10 ϕ	2698.8	8 ϕ
3403.5	10 ϕ	22	
15–16		2663.6	8 ϕ
3180.8	10 ϕ	2659.0	8 ϕ
3132.2	10 ϕ	2653.6	8 ϕ
17		23	
3050.9	8 ϕ		
3030.4	Group ϕ		
18			
3015.3			

SILICON

The lines of silicon do not develop in acid solutions, and quite large quantities may be present in acid solutions of other elements without giving any indication of their presence when sparked; so that for the detection of silicon, it is absolutely essential to spark an alkaline solution. The group a little beyond gold line No. 25 is very characteristic, and easily recognized.

TABLE V

QUANTITATIVE SPECTRUM OF SILICATE OF SODA

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
4131.0	4 ϕ	24–25	
4128.2	4 ϕ	2528.6	8 ψ
12		2524.2	6 ϕ
3905.8	5 ϕ	2519.3	8 ϕ
13		2516.2	10 ψ
2881.7	10 ϕ	2514.4	7 ϕ
20–23		2507.0	8 ϕ
2631.4	8 ϕ		

ZINC

Zinc has a strong line coincident with gold line No. 16, and another with the gold line just beyond No. 20. As in the case of aluminium, quite a number of lines develop strongly with the metal and strong solutions, but not with dilute solutions; these are marked σ in the following table:

TABLE VI

QUANTITATIVE SPECTRUM OF ZINC CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
8		18	
4810.7	10 ϕ	3018.5	4 σ
9		19–20	
4722.3	10 ϕ	2801.0	8 ϕ
4680.4	10 ϕ	2771.0	8 ϕ
10–15		2756.5	6 ϕ
3345.3	10 χ	21	
3303.0	10 χ	2712.6	2 σ
3282.4	10 χ	2684.3	2 σ
16–17		22–24	
3076.0	8 σ	2582.6	2 σ
3072.2	10 σ	2570.0	2 σ
3035.9	8 σ	2558.0	10 χ

TABLE VII

QUANTITATIVE SPECTRUM OF MANGANESE CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
4823.7	8 σ	3460.5	10 ϕ
9		3442.1	10 ϕ
4783.6	6 σ	15–18	
10–11		2949.3	10 χ
4083.8	6 σ	2939.4	8 χ
12		2933.1	8 χ
4055.7	6 σ	19	
4048.9	6 σ	2879.5	6 ϕ
4041.5	6 σ	20–21	
4035.9	6 σ	2705.7	6 ϕ
4034.6	6 σ	22	
4033.2	6 σ	2701.7	6 ϕ
4030.9	8 χ	23	
13		2639.9	6 ϕ
3823.6	6 ϕ	2632.5	6 ϕ
3806.9	10 ϕ	2625.7	6 ϕ
14		2618.2	6 ϕ
3496.0	8 ϕ	2605.8	10 ω
3488.8	10 ϕ	2594.0	10 ω
3483.0	10 ϕ	24	
3474.2	10 ϕ	2576.2	10 ω

MANGANESE

The spectrum given by the metal is practically identical with that of a strong solution. The three ω lines in the region of gold line No. 24 form a very characteristic group, by which this element can be rapidly identified. The general results are as shown in Table VII.

NICKEL

The plates show that the same lines are developed by the metal and strong solutions; the relative rate of disappearance of the lines on dilution is shown in the table:

TABLE VIII

QUANTITATIVE SPECTRUM OF NICKEL CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
3619.5	10 ϕ	3134.3	8 χ
3597.8	10 ϕ	17	
14		3102.0	8 χ
3566.5	10 ϕ	3101.6	8 χ
3524.6	10 χ	3064.7	7 ϕ
3515.2	10 χ	3057.7	8 ψ
3510.5	10 χ	3054.4	7 ψ
3493.1	10 χ	3050.9	8 ψ
3472.7	8 ϕ	3038.0	7 χ
3446.3	8 χ	18	
3433.7	7 χ	3012.1	8 χ
3423.8	7 ϕ	3003.7	8 χ
3414.9	8 ψ	19–23	
3393.1	7 ϕ	2546.0	7 ϕ
15		24–25	
3247.7	7 ϕ	2510.9	8 ψ
3233.1	8 ϕ		

COBALT

Like iron, manganese, and nickel, cobalt gives the same lines with the metal and strong solutions. The results of dilution are given in Table IX.

After sparking the strong solutions, it was found that in many cases the electrodes alone gave quite strong spectra of the metal under examination, and at first it was supposed that the solutions had sprayed on to the fresh electrodes; but on keeping the fresh electrodes in another room, no difference was observed, and in the case of an element such as iron or calcium, the dilution spectra could not be

TABLE IX

QUANTITATIVE SPECTRUM OF COBALT CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
4531.1	4 σ	3412.8	7 φ
10		3405.3	8 ψ
4469.7	1 σ	15–17	
4121.5	8 φ	3086.9	6 φ
4118.9	8 σ	3072.5	6 φ
12		18–21	
3995.5	8 φ	2694.7	8 ω
13		22	
3894.2	10 ψ	2663.6	8 χ
3873.2	10 ψ	23–24	
3845.6	10 φ	2587.2	8 φ
14		2582.3	8 χ
3502.4	8 χ	2580.4	8 ψ
3489.5	10 φ	2564.2	8 φ
3474.1	10 χ	2559.5	8 χ
3465.9	8 φ	25	
3453.6	8 ψ	2528.7	7 χ
3449.6	7 φ	2525.1	7 χ
3443.8	7 φ	2519.0	8 ω
3433.2	7 φ		

followed beyond the 0.1 per cent. solution, as the electrodes then gave as strong spectra as the solutions. It was then seen that the atmosphere was charged with the element, and remained charged for a considerable time. In the following investigations the difficulty was got over by beginning with the most dilute solution, and working backward toward the strong solutions, finally sparking the metal when it could be procured.

The photographs of spectra extend from λ 5900 to λ 2500; but the plates were not very sensitive below λ 4792.8, nor was the instrument in perfect focus beyond λ 2590.2.

It is a remarkable fact that the residuary lines of an element differ greatly with the method of excitation, and there is no guarantee that the residuary lines here tabulated would be the most persistent lines if the substances were vaporized by something other than the condensed spark; certainly, in the case of the oxyhydrogen flame, there is a notable difference; thus, with manganese, we have shown that, when the condensed spark is used, the residuary lines are λλ 2605.8, 2594.0, and 2576.2; but if the oxyhydrogen flame be employed to vaporize the element or its compounds, the residuary lines, as

shown by Professor Hartley,[1] are λλ 4034.6, 4033.2, 4030.9; and in general, we note that, with the oxyhydrogen flame, the residuary lines tend to the less refrangible end of the spectrum; but with the condensed spark they tend to the more refrangible end. Apparently the nature of the dilutant has no effect on the residuary lines; thus the same residuary lines would be obtained whether the metal was in the form of a dilute solution or alloyed with another metal; but we have not yet investigated whether the degree of persistency is affected; probably it would be influenced by the relative volatility of the diluting metal in the alloy, and the sensitiveness greatly reduced owing to the vapor of the dilutant being itself a conductor, so that in an alloy one would not readily detect the presence of less than 0.1 per cent. of a substance. In tabulating the results, when the intensities were other than those usually accepted, they are inclosed in brackets.

BARIUM

The salt used was barium chloride; and the most persistent lines were situated in the visible part of the spectrum, the residuary lines being λλ 4554.2, 4130.9. As metallic barium is not easily procured in a state of purity, we were unable to determine whether any lines are developed by the metal, but not by solutions.

TABLE X

QUANTITATIVE SPECTRUM OF BARIUM CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
5535.7	10 ϕ	4283.3	8 σ
5519.4	4 ϕ	4166.2	10 ϕ
5524.8	6 σ	4130.9	10 ω
4934.2	10 ψ	[No. 12,	Gold.]
4900.1	[8] σ	3993.6	8 σ
[No. 9,	Gold.]	3910.1	6 σ
4726.6	[3] σ	[No. 13,	Gold.]
4691.7	[3] σ	3892.0	10 ψ
4673.7	[3] σ	[No. 14,	Silver.]
4554.2	10 ω	3501.3	8 σ
4525.2	10 χ	[No. 15,	Silver.]
4506.1	6 σ	3357.0	[4] σ
[No. 10,	Gold.]	[No. 20,	Gold.]
4432.1	8 σ	2771.5	8 ϕ
4402.7	8 σ	[No. 23,	Gold.]
4350.5	6 σ	2634.9	8 ϕ
[No. 11,	Gold.]		

[1] *Phil. Trans.*, **185**, Part I, 161–212, 1894.

STRONTIUM

Strontium chloride was the salt used. The most persistent lines were situated in the visible part of the spectrum, residuary lines λλ 4607.5, 4305.6, 4215.7, and 4077.9 being faintly seen with a dilution of $\frac{1}{100000}$. As in the case of barium, we were unable to test the difference between the spark-spectrum of the metal and a strong solution.

TABLE XI

QUANTITATIVE SPECTRUM OF STRONTIUM CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
5535.0	8 σ	4607.5	10 ω
5522.0	8 σ	[No. 11,	Gold.]
5504.5	8 σ	4305.6	30 ω
5486.4 }	6 } φ	4215.7	100 ω
5481.1 }	10 } φ	4162.0	20 φ
5451.1	5 σ	4077.9	100 ω
5257.1	8 σ	[No. 12,	Gold.]
4962.4	8 φ	4032.5	[4] σ
4876.3	6 σ	[No. 13,	Gold.]
4832.2	6 σ	3475.0	20 φ
4812.0	6 σ	3464.6	100 φ
[No. 9,	Gold.]	[No. 15,	Silver.]
4742.1	6 σ	3380.9	80 σ
4722.4	6 σ	3351.3	3 χ

CALCIUM

Calcium chloride was the salt used; and, as in the case of barium and strontium, the most persistent lines were situated in the visible part of the spectrum, the residuary lines being λλ 4226.9, 3968.6, and 3933.8. On taking the spark-spectrum of the metal, it was found to contain magnesium, manganese, and silicon; but in addition to the residuary lines of these elements, which are all situated in the ultra-violet part of the spectrum above gold line No. 18, the metal showed one or two very well-defined and intense lines that are either not shown at all by strong solutions, or only faintly shown: those lines are marked τ in the table. The dilution-spectrum of calcium was investigated by Sir William and Lady Huggins in a manner differing somewhat in detail from that adopted in the present experiments; but the conclusions are the same as regards the identity of the residuary lines.

TABLE XII

QUANTITATIVE SPECTRUM OF CALCIUM CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
5594.6	8 σ	4289.5	8 ϕ
5270.5	8 σ	4283.2	8 ϕ
4878.3	6 σ	4226.9	10 ω
[No. 9,	Gold.]	[No. 12,	Gold.]
4586.1	4 σ	3968.6	80 ω
4581.7	4 σ	3933.8	100 ω
4527.2	[4] σ	[No. 13,	Gold.]
4455.0	10 ϕ	3737.2	15 ψ
4435.1	10 ϕ	3706.2	10 ψ
4425.6	10 ϕ	3644.5	2 ϕ
4318.8	8	3630.8	1 ϕ
[No. 11,	Gold.]	[No. 14,	Silver.]
4307.9	6 σ	3179.4	10 χ
4302.7	10 σ	3159.1	10 χ
4299.1	6 σ	[No. 17,	Gold.]

MAGNESIUM

Magnesium chloride was the salt used. Unlike barium, strontium, and calcium, the most persistent lines are situated in the ultra-violet part of the spectrum, the residuary lines being $\lambda\lambda$ 2852.2, 2798.2, and 2790.9.

TABLE XIII

QUANTITATIVE SPECTRUM OF MAGNESIUM CHLORIDE

Wave-Length	Intensity and Persistency	Wave-Length	Intensity and Persistency
5528.7	6 ϕ	[No. 17,	Gold.]
5183.8	10 ϕ	3097.1	[8] ϕ
5167.6	8 ϕ	3093.1	[8] ϕ
[No. 9,	Gold.]	[No. 18,	Gold.]
4703.3	[8] τ	2937.0	10 χ
[No. 10,	Gold.]	2928.7	10 χ
4481.3	10 σ	2915.5	10 σ
4352.2	[8] τ	2852.2	10 ω
[No. 13,	Gold.]	[No. 20,	Gold.]
3838.4	10 σ	2798.2	8 ω
3832.5	10 σ	2790.9	10 ω
3829.5	10 σ	2783.1	4 ϕ
[No. 15,	Silver.]	2781.5	4 ϕ
3336.8	8 σ	2779.9	6 χ
3332.3	8 σ	2778.4	4 ϕ
3330.1	6 σ	2776.8	4 ϕ

The metal gives one or two strong lines that are not seen, or only very faintly seen, with strong solutions. Those lines are marked τ.

The quantitative spectrum of magnesium was previously investigated by Professor W. N. Hartley, and his results are in accordance with the present observations; but as previously explained, Professor Hartley's method of observation gave a greater quantity of vapor, and an apparently greater persistency of the lines; but the relative persistencies are substantially the same, and the residuary lines are identical.

POTASSIUM

Photographs were taken with metallic potassium in an atmosphere of hydrogen, and also with solutions of potassium chloride.

Potassium is characterized by a very feeble spark-spectrum, only two lines showing with one minute's exposure either with the metal or a saturated solution; and with a 1 per cent. solution they are scarcely visible. It is remarkable that the flame-spectrum is very intense; apparently the temperature of the oxyhydrogen flame, or even the Bunsen, gives a far more brilliant spectrum than the condensed spark. This is, no doubt, owing to the greater quantity of vapor produced.

TABLE XIV

QUANTITATIVE SPECTRUM OF POTASSIUM CHLORIDE

Wave-Length	Intensity and Persistency
4047·4	10 ϕ
4044·3	10 ϕ
3447·5	(8) σ
3446·5	(8) σ

SODIUM

Sodium chloride was used for the solutions, and the metal was photographed in an atmosphere of hydrogen. Sodium gives a well-marked spectrum of three pairs of lines; but, with the exception of the D lines, they are not very persistent; and, as in the case of potassium, the sodium lines do not show with the spark nearly so strongly as with the oxyhydrogen flame, or even the Bunsen burner.

It is also very remarkable that the D lines do not seem to show as strongly with the metal as with a strong solution of the chloride.

TABLE XV

QUANTITATIVE SPECTRUM OF SODIUM CHLORIDE

Wave-Length	Intensity and Persistency
5896.2	10 ω
5890.2	10 ω
5688.3	6 ψ
5682.9	6 ψ
3303.1	10 χ
3302.5	10 χ
2852.9	(6) σ

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ON SOME DEVICES FACILITATING THE STUDY OF SPECTRA[1]

By WALTER NOEL HARTLEY

It has been shown in previous communications that flame-spectra at high temperatures have a special value, inasmuch as minute traces of metallic and mineral substances may be readily detected, and their spectra photographed; for instance, from iron ores and pig-iron as many as ninety lines of the element are photographed at one exposure.[2]

The source of heat being the oxyhydrogen flame, the temperature lies between 1400° and 2000°; and as 1775° is about the melting-point of platinum, some other support than that metal must be used for solid substances. Thin slips of Donegal cyanite and ashless filter-papers have been used almost exclusively, and their use described in the publications quoted. The cyanite consists of 98.0 per cent. of aluminium silicate, according to an unpublished analysis made in my laboratory; it merely softens in the flame, and it is useful for long exposures of half an hour or upward. The lines of sodium and lithium in the yellow and red are the only impurities which are photographed. The filter-papers are useful for rapid exposures of one to two minutes; they yield the sodium line only; but atmospheric dust settles upon them, and consequently feeble red and green bands of calcium sometimes appear, especially when ten filter-papers are used for one spectrum. Cyanite is not always procurable, but carborundum is now an article of commerce.

Carborundum.—This gives no spectrum in the oxyhydrogen flame; it is incombustible, and quite infusible. This material in a form adapted for supports is manufactured by the Carborundum Company for other purposes, the small crystals being mixed with porcelain clay, and fired at a high temperature. Thin, flattened

[1] *Scientific Proceedings of the Royal Dublin Society*, 11, No. 19, August 1907.

[2] W. N. Hartley, "Flame-Spectra at High Temperatures," *Phil. Trans.*, *A*, **185**, 161–211, 1894.

Hartley and Ramage, "A Simplified Method for the Spectrographic Examination of Minerals," *Chem. Soc. Trans.*, **79**, 61, 1901.

pieces, four inches in length and $\frac{1}{16}$ of an inch in thickness, are sold as silversmith's stones. It is advisable that this material be cautiously introduced into the flame.

Quartz fibers and thin rods.—At the melting-point of platinum quartz only softens; hence this material, which is now manufactured by Messrs. Johnson & Mathey, in the form of rod and tube, is available for use. The quartz, as a rule, gives no impurity lines.

The Mecke burner.—In all the various forms of smokeless burners which have been devised, the chief defect lies in the small area of the cross-section of the flame which provides the maximum temperature; great variations in temperature arise from the irregularity of the flame, when subject to the influence of draughts, especially horizontal currents of air. From these defects the Mecke burner is entirely free; and for ordinary spectroscopic purposes I can recommend no other. Its construction is that of a Gifford's injector, the current of gas injecting into the tube the requisite amount of air necessary for its complete combustion. In order to admit of the gas and air being mixed together, two metallic gratings are placed within the tube of the burner; and about half an inch above the upper grating a cap consisting of a third grating is fitted. As the upper part of the tube is choked by the gratings, it is expanded to compensate for this. To ignite the mixture of gas and air, the match-flame must not be held above, but close to the grating. Supposing the diameter of the top of the burner be two centimeters, the gaseous mixture is seen to burn from about thirty-seven little jets, each of which shows a green cone if the air is excessive, but a blue one if the mixture is of the right nature to obtain the highest temperature. The maximum heating effect is from two to three millimeters above the grating; and it is equable across the whole diameter of the tube. Platinum wire of the ordinary thickness just fuses upon the surface. The shape of the flame is a cone about 25 mm high, and therefore pyramidal. Draughts do not affect the flame. In the Mecke burner, fused alkali and alkaline earth-salts are easily examined on platinum wire, hard asbestos fibers, quartz fibers, or on tobacco-pipe. It is, of course, necessary to ascertain what spectrum-lines the support yields, and eliminate the lines or bands from the spectra subsequently observed. Quartz fibers and platinum obviously yield nothing.

Fusible silicates, such as lepidolite, show the spectra of potassium, lithium, and, with a wide slit, even of rubidium. A convenient way of examining solutions is to employ a clay tobacco-pipe, to plug the mouthpiece of the pipe with two or three asbestos fibers, and to pour the solution into the bowl. By inclining the pipe, the solution soaks through the asbestos, the water evaporates, and the salt fuses on the fibers. Similarly, a piece of quartz tube is drawn out to a capillary point, the end being left open; the solution then issues in drops, which dry upon the point of the tube; it is the solid salt, and also spray from the solution, which yields the spectrum. The quartz is unbreakable by the contact of the hot material with a cold solution. When even white-hot, it may be dropped into cold water without cracking, or into hydrochloric acid in order to cleanse it.

The Mecke blast-burner.—This modification, in addition to the injector, has an air-jet placed higher up in the tube. The air-blast must be supplied with a regulated constant-pressure, which may be obtained in any way, as by bellows, a rotary fan, or tromp; but the pressure should not be less than two kilograms per square centimeter. With water direct from the high-pressure mains, the water-blower is satisfactory; but the instrument should be fitted with a pressure-gauge. A blower fitted up twenty-five years ago has been found generally effective. The essential parts are a Körting's jet soldered on to a water-tap, to which again the inlet-tube of the blower is soldered. The air-reservoir is a tube 4 feet long by 3 inches broad. Platinum wire, of the usual thickness suitable for spectroscopy, is easily melted n the flame at its hottest part; and therefore quartz-fibers are a suitable material to use as supports. To convey some idea of the advantages gained by the use of these burners for spectroscopic work, I may mention that the use of fused salts or infusible compounds is to be preferred to aqueous solutions, or to substances strongly acidified with hydrochloric acid. Thus the examination is simplified and made more cleanly in manipulation. Any salt previous to being examined should be heated in a covered porcelain crucible until it ceases to decrepitate or evolve water; it is then in a suitable condition to be placed on the support.

In the practical use of the flame spectra there is no difficulty in recognizing traces of the alkalis by their lines; but with salts of

the alkaline earth-metals, the most characteristic feature of their spectra is bands, and not lines. The usual mode of examination in the Bunsen flame is to moisten the solid substance with hydrochloric acid, to take some of this up on a platinum wire and place it in the flame, when a momentary brilliant flash follows; after a short interval very little of the spectrum remains to be seen, and what there is has an essentially different appearance. It is hardly necessary to point out that volatile metallic chlorides yield the first spectra; and those subsequently visible are the spectra obtained, first by the conversion of the chlorides into oxides, and secondly by the reduction of oxides to the metallic state and the coloration of the flame by the metals.[1]

By employing the high temperature of a Mecke burner even of the simple pattern, the second spectra are rendered constant for a long period, even if the oxides or sulphates are employed. Accordingly what distinguishes the least trace of calcium is a red band and a green band, one on each side of the sodium line. Strontium yields two red bands and one orange band. As a rule, neither the blue line of calcium nor the corresponding blue line of strontium is plainly seen. If any calcium salt be placed in the flame, the effect first seen is a strong sodium spectrum; but the heat is so intense that the sodium is soon volatilized; and nothing but the red coloration of the calcium remains; though this may continue for an hour or longer, and may be photographed. The red and green bands have been obtained from calcium chloride, calcium nitrate, calcium carbonate, calcium sulphate, and from quick-lime. The photograph of the bands taken from calcium nitrate during one hour's exposure in a simple Mecke burner shows the essential features of the calcium spectrum. The slit was sufficiently narrow to divide the two sodium lines when very minute quantities of sodium were present.

A device for showing chloride spectra.—When an oxide is supported in the flame of a Mecke burner, it may be made to yield a chloride spectrum by introducing a few fibers of asbestos or tobacco-pipe upon which is crystallized some ammonium chloride. The effect is, however, evanescent; and to operate continuously over long periods,

[1] W. N. Hartley, "On the Thermo-Chemistry of Flame-Spectra at High Temperatures," *Proc. Roy. Soc.*, *A*, **79**, 242–261, 1907.

the burner is supplied with gas mixed with the vapor of chloroform in exactly those proportions which give the best effect. The gas may be taken from two separate taps, or from a tube with a by-pass; one-half of the gas to be burnt goes through a bottle containing sponge saturated with chloroform. The outlet tube from the bottle is joined to one end of a λ piece; the gas is joined to the other; while a single tube goes to the burner. By regulating the two taps, the most brilliant spectra may be made to continue for several hours without trouble; and the spectra may be photographed.

On measuring spectra.—In making observations of the visible spectrum, measurements made with cross-wires in the eye-piece of the telescope are seldom quite concordant when series of measurements are made throughout the whole spectrum, first in one direction and then in the other; the differences are greater in the measurements of bands than in those of lines. This is due to two causes, the one, an alteration in the focus of the eye; the second, slight variations in the width and intensity of the bands. To counteract the first difficulty I have had two instruments made with graduated draw-tubes, and have marked the focus as determined for red, yellow, green, blue, and violet lines, such as lines of potassium, lithium, sodium, thallium, strontium, calcium, and a spark-line of magnesium. Of course the focusing is adapted to only one eye-piece. In measuring green rays the telescope is adjusted for the thallium line as marked upon the scale; and other measurements are easily made on either side of this. Each observer must focus for himself. In the measurements of bands the Mecke burner offers a decided advantage over the ordinary Bunsen flame, because it is not subject to fluctuations in temperature, and is on the whole hotter, being about 1400° C. throughout the body of the flame; the bands are therefore of uniform brilliancy and width. But, above all, the bands may be photographed, so that with the same photographic plates and the same exposure a similar spectrum is obtained, which can be measured by applying an ivory scale divided into hundredths of an inch, or fourths of a millimeter; and measurements may be repeated and corrected. Eye-observations record the average effect of brilliancy and intensity of lines and bands; while photographs are a record of the aggregate effect over a given period of time. All difficulties arising out of

inequality in sensitiveness of the prepared film to different colors are now overcome by the use of Wratten and Wainwright's panchromatic plates. The examples of flame-spectra of the calcium, strontium, and barium group show that, with a constant exposure, the width of the bands increases with the quantity of substance in the flame; with a constant quantity of substance and varying exposures, the width and intensity of the bands increase with the exposure. With certain elements the bands are widened and intensified more on the less refrangible side; with others, on the more refrangible. This explains what has been remarked by von der Seipen,[1] namely, that, between his measurements of the bands of metallic tin and mine, there is a large though constant difference in the wave-length values; and he attributes this to the old normal wave-lengths of Ångström being used. The difference, however, between the two sets of measurements amounts to from 4 to 7 Ångström units, but over the same range of spectrum the maximum difference between Hartley and Adeney's wave-lengths (1884) and Rowland's (1893)[2] is, at most, +1.1 Å unit, the minimum being +0.4, and the average something less than +0.8.

There is no doubt that my spectrum was photographed from a much larger quantity of material; and the exposure was also longer; and therefore the bands were broader and more intense.

[1] "Ueber das Flammenspektrum des Zinns," *Zeitschrift für wissenschaftliche Photographie*, **5**, 69–85, 1907.

[2] J. F. Eder, "Beiträge zur Spectralanalyse," *K. K. Akad. Wissensch.*, Vienna, **60**, 13, 1893.

A SUGGESTION TOWARD THE EXPLANATION OF SHORT-PERIOD VARIABILITY

By F. H. LOUD

Mr. Ralph H. Curtiss, in the *Astrophysical Journal* (**20**, 186, 1904), remarks, "It is easy to construct a plausible explanation for the light- and velocity-curves of *W Sagittarii* on the assumption that the system is pervaded by a resisting medium which enhances the brightness of that side of the star which faces the direction of motion. . . . . Until more data are available, it would be premature to follow out such theories."

The hypothesis as to the cause of short-period variability, which is here applied to a single star, having independently occurred to me—as no doubt to many others, and perhaps to some before Mr. Curtiss—I was looking through the *Astrophysical Journal* for data bearing upon its verification, when I came upon the above sentence. I desire to discuss briefly the conformity of the hypothesis with known facts, a few of them later in date of publication than the article above quoted.

It should first be observed that the special feature of *W Sagittarii* which appears to have prompted Mr. Curtiss' remark was the discovery that the light- and velocity-curves of this star are so related that approach to the earth is accompanied by brilliancy above the average, and recession from it by comparative faintness; this relation holding true not merely in a normal elliptical motion, but throughout a remarkable disturbance of the latter which characterizes this individual orbit, thus indicating that the star is bright or faint according as its advancing front is presented or not to our view.

A recent collection of all the instances, ten in number, in which the light- and velocity-curves of variables of this class have been examined, made by Mr. Sebastian Albrecht in the course of his original discussion[1] of two of them, has brought out the notable fact that this relation between approach and brilliancy holds good throughout the list and is apparently characteristic of the δ *Cephei* type of variables. This fact, due to Dr. Albrecht's own research, of course immensely strengthens the validity of the assumed cause, to which, however,

[1] *Lick Observatory Bulletin*, No. 118, p. 138; *Astrophysical Journal*, **25**, 330, 1907.

the memoir of this astronomer makes no allusion. But the decisive test of the hypothesis must lie in its ability to account for the phenomena which characterize these variables as a class.

Of these, one of the most noteworthy is the rapid rise of the light-curve before maximum, followed by a decline which occupies, on the average, double the time of increase, and often much more. A few instances in which this peculiarity was deemed to be replaced by symmetry have been erected on that ground by some authorities into a separate species, having *ζ Geminorum* for a type. But it is doubtful whether a satisfactory instance of actual symmetry exists.

In the case of *ζ Geminorum* itself, the bisection of the period by the extreme phases, though very approximate, is not exact; while a secondary fluctuation of light preceding the principal maximum, and partially harmonizing with the disturbance of velocity discovered by Campbell, was reported by F. P. McDermott.[1]

In *U Vulpeculae*, too, the equality at first claimed is contested, and if the regularity of *RR Centauri* is as yet unimpeached, it would be hazardous to predict that it will remain so. On the other hand, the usual asymmetry is in no way fixed in degree, varying in sundry instances much below the mean; thus in *W Virginis* the time of increase is to that of decrease as 46 to 54; while *S Antliae*, according to Professor E. C. Pickering, exhibits a corresponding ratio of 62 to 38, thus for once overpassing the limit of symmetry. These stars must then be regarded, at least provisionally, as merely aberrant members of the class represented by *δ Cephei*.

On the other hand, the type represented by *β Lyrae* is entirely distinct. In the latter the maxima do not coincide with the times of most rapid approach; moreover, the character of the spectrum is clearly Sirian, while the variables of the class here considered are without exception either solar, or still farther removed from the Sirian type.[2] I do not propose in this paper to enter upon the dis-

[1] *Astrophysical Journal*, 16, 117, 1902.

[2] Of the 81 variables referred to Class IV in Miss Cannon's "Second Catalogue of Variable Stars" (*Annals H. C. O.*, 55, Part I), when the *β Lyrae* stars, with *U Leporis*, have been removed, as well as those whose spectra have not been satisfactorily examined, there remain 45, classified spectroscopically as follows: *F*, 6; *F2G*, 1; *F5G*, 6; *F8G*, 1; peculiar, but between *F* and *G*, 1; *G*, 12; *G5K*, 7; *K*, 4; *K5M*, 5; spectra continuous or nearly so, 2.

cussion of the cluster-type of variables, to which the name Antalgol has been applied by Hartwig. Of the isolated stars, like *Y Lyrae*, which conform to this type, none (unless *U Leporis*, which is Sirian, be classed among them) is of sufficient brightness to have yet permitted a satisfactory determination of its spectroscopic species, much less to afford a velocity-curve; and in the absence of the latter no theory of light-change can be verified.

The best-known and most representative stars of the class under discussion, are then, stars of advanced development, and at the same time binaries of short period, in which as a rule one component only of the pair is luminous, for the spectral lines undergo no periodic duplication. According to the hypothesis to be tested, this component owes its light to the resistance of a diffused medium, to which the other must be assumed to be relatively at rest. The visible star, then, is the satellite; and at so short a distance from the primary, the tides necessarily induced tend to impose upon it a rotation of equal rate with its revolution. The orbital movement, however, in parting with the energy which becomes the source of the star's visibility, is continually drawn into narrower compass, and thus accelerated in speed. The tidal action tends to restore the equality of the periods, with the result that the rotation is always a little—but only a little—slower than the revolution. The effect of this lag is that the area on the satellite, heated to brilliant incandescence, is of an unsymmetrical form. The point of greatest heating, since it occupies the momentary center of the advancing front, moves in consequence slowly around the equator, always entering upon regions comparatively cool, and drawing behind it regions glowing from their recent exposure to heat. Thus, as the revolution brings these regions successively into the line of sight, there appears first, to our view, a sudden rise of brightness, then, after the maximum, a long and gradual decline. The degree of cohesion in the surface, implied in this account, might well be too great for a star of Sirian tenuity, but not for the class of bodies actually concerned; especially if it be considered that both primary and satellite are presumed to have advanced far in condensation, with accompanying loss of light, the latter body being probably as dark as the former, save for the surface action of the resistance.

Exceptional cases of the disappearance or reversal of the usual asymmetry would occur if the rate of rotation should be equal to that of revolution, or more rapid—a condition which certainly might now and then be present, from various conceivable causes.

It seems quite in accordance with the hypothesis under consideration that the maxima, depending as above upon the visibility of a highly heated region, should show a special accentuation of the light of short wave-length; and both Albrecht and Wilkens find this to be distinctly the case.

On the other hand, an objection is apparent in the fact that the moment of most rapid approach to the earth, which might be expected from the hypothesis to occur—if on either side—a little before the maximum of brilliancy, appears from the published measurements to come more commonly after it. In the type-star, indeed, δ *Cephei*, and also in *T Vulpeculae*, one of the stars examined by Mr. Albrecht, the expected relation is confirmed by observation, but in seven others the contrary holds. The discrepancy between the times of extreme phase in the curves of light and velocity is in no case large, but varies from zero to nearly 8 per cent. of the period, which is its value in *Y Ophiuchi*, the other of Mr. Albrecht's stars. As the period of this star is unusually long, the mean interval amounts in this case to a day and three-tenths; and the observations leave little doubt of the reality of the phenomenon. Its recognition, however, is not necessarily fatal to the hypothesis. One way of reconciling the latter to the fact might be to imagine that the impact of the nebulous particles upon the star induces an increase not only of heat but of general absorption; then the maximum brilliancy might precede the greatest frequency of impact in very much the same way as the maximum light of a Colorado summer day, in consequence of afternoon clouds, occurs a little before noon. If it be granted that, under such circumstances, the radiation of short period would be first to receive a check to its growing intensity, we may find a confirmation of this suggestion in the fact that the photographically determined light-maximum of *T Vulpeculae* appears from the measurements of Wilkens to precede by a perceptible interval that obtained from visual observations. In fact, if the time of light maximum deduced by this observer be accepted, this star no longer forms with δ *Cephei*

an exception to the prevailing rule of arrangement, but takes its place with the majority.

Another well-known but by no means constant feature of the light-curves of this class of variables is that described by Miss Clerke[1] as "an inherent tendency to a second maximum, sometimes barely indicated as a pause in descent, but in several cases giving rise to a pronounced 'hump' in the downward slope of the light-curve."

Secondary fluctuations in brightness, on the theory proposed, might be produced in at least three different ways:

a) The orbit, which has thus far been discussed as if it were circular, is in fact, of course, generally elliptical; and the epoch of periastron must be marked by more intense heat, due to greater velocity of motion.

b) The orbital eccentricity will occasion a libration[2] which will modify the above-mentioned lag of rotation. For instance, if it happen that the time of greatest negative velocity in the line of sight nearly coincides with that of apastron, the orbital movement, temporarily reduced in velocity, may perchance be of about equal speed with the rotation. This has been mentioned as the condition for symmetry in the light-curve, and the latter may accordingly present such an appearance at its summit, with a pronounced "hump" further on, where the gain of the revolution on the rotation has become marked.

c) The resisting particles, instead of forming a stationary and uniform medium, may have an unequal distribution or an independent motion. This third condition, it would appear, must prevail in instances like *T Monocerotis*, when the amplitude of variation is inconstant. Its consideration will, on the other hand, be excluded whenever—as in the greater number of stars—such a feature is absent.

Recurring to the other two specifications, (*a*) and (*b*), which are

[1] *Problems in Astrophysics*, p. 320.

[2] The term "libration"—here used by reason of its suggestiveness of the relation between the two movements—is perhaps not altogether appropriate, since the visibility of a particular point of the surface from an infinite distance depends, of course, on rotation alone. The actual effect of the varying rapidity of revolution will be to elongate the area of maximum heating at periastron and contract it at apastron, its forward movement on the surface being accelerated at the former aspect and checked at the latter.

both dependent upon the ellipticity of the orbit, it is to be remarked that the fact that their efficiency must combine in an unknown proportion will render difficult what would otherwise appear a promising test of the hypothesis, applicable in all cases in which the eccentricity and the position of the line of apsides is known from the curve of velocity. Together, they may well occasion, in some instances, two subordinate waves in the light-curve, which in other cases may be blended; nor should the three maxima be expected to conform to any easily distinguishable rule as to their distribution through the period.

COLORADO COLLEGE
August 30, 1907

THE EFFECT OF PRESSURE UPON ARC SPECTRA[1] NO. I.—IRON

By W. GEOFFREY DUFFIELD

The first part of the paper contains a description of the mounting and adjustment of the large Rowland concave grating in the Physical Laboratory of the Manchester University. The feature of this is the stability of the carriages carrying the grating and camera, and the novel construction and attachment of the cross-beam, which secure the absence of any disturbance which might be caused by bending or sagging.

The second part describes experiments made with a pressure cylinder designed by Mr. J. E. Petavel, in which an arc is formed between metal poles opposite a glass window, through which the light is examined by means of the grating spectroscope. A system of mirrors allows the image of the arc, however unsteady it may be, to be kept almost continuously in focus upon the slit.

Two sets of photographs of the iron arc in air have been taken for pressures ranging from 1 to 101 atmospheres (absolute), and the results are given below for wave-lengths $\lambda = 4000$ Å.U. to $\lambda = 4500$ Å.U.

I. BROADENING

1. With increase of pressure all lines become broader.

2. The amount of broadening is different for different lines, some almost becoming bands at high pressures, and others remaining comparatively sharp.

3. The broadening may be symmetrical or unsymmetrical; in the latter case the broadening is greater on the red side.

II. DISPLACEMENT

1. Under pressure the most intense portion of every line is displaced from the position it occupies at a pressure of 1 atmosphere.

2. Reversed as well as bright lines are displaced.

[1] Abstract of a paper communicated by Professor A. Schuster to the Royal Society, July 4, 1907.

3. With increase of pressure the displacement is toward the red side of the spectrum.

4. The displacement is real and is not due to unsymmetrical broadening.

5. The displacements are different for different lines.

6. The lines of the iron arc can be grouped into series according to the amounts of their displacements.

7. Three groups can in this way be distinguished from one another; the displacements of Groups I, II, III bear to one another the approximate ratio 1:2:4. (The existence of a fourth group is suggested by the behavior of two lines, but further evidence is needed upon this point; 1:2:4:8 would be the approximate relations existing between the four groups.)

8. Though all the lines examined, with two possible exceptions, fall into one or other of these groups, the lines belonging to any one group differ to an appreciable extent among themselves in the amounts of their displacements.

9. The relation between the pressure and the displacement is in general a linear one, but some photographs taken at 15, 20, and 25 atmospheres pressure give readings incompatible with this relation. Other photographs at 15 and 25 atmospheres present values which are compatible with it.

10. The abnormal readings are approximately twice those required by the displacements at other pressures, if the displacement is to be a continuous and linear function of the pressure throughout.

11. On the photographs showing abnormal displacements the reversals are more numerous and broader than they are on plates giving normal values, and there is some evidence in favor of a connection between the occurrence of abnormal displacements and the tendency of the lines to reverse.

III. REVERSAL

1. As the pressure is increased, reversals at first become more numerous and broader.

2. The tendency of the lines to reverse reaches a maximum in the neighborhood of 20 to 25 atmospheres, and a further increase in pressure reduces their number and width.

3. Two types of reversal appear on the photographs, symmetrical and unsymmetrical.

4. Within the range of pressure investigated, the reversals show no tendency to change their type.

5. In the case of unsymmetrically reversed lines in the electric arc, the reversed portion does not in general correspond to the most intense part of the emission line, being usually on its more refrangible side.

6. The displacements of the reversed parts of the unsymmetrically reversed lines of Group III are about one-half the displacements of the corresponding emission lines. Indeed, the reversed parts of the lines of Group III fall approximately in Group II.

7. No relation between the order of reversal and the frequency of vibration, such as exists in the spark, has been observed in the iron arc for the ranges of wave-length and pressure examined.

IV. INTENSITY

1. The intensity of the light emitted by the iron arc is, under high pressures, much greater than at normal atmospheric pressure.

2. Changes in relative intensity of the lines are produced by pressure. Lists of enhanced and weakened lines are given.

Reviews

A REDETERMINATION OF THE LENGTH OF THE METER IN TERMS OF THE WAVE-LENGTH OF THE RED CADMIUM LINE

In the issue of *Comptes Rendus* for May 21, 1907 (**144**, 1082–1086), Messrs. Benoit, Fabry, and Perot briefly state the results of this work, which they have been conducting at the laboratory of the Conservatoire des Arts et Métiers. The highly satisfactory outcome is that the earlier determination by Michelson, made at the International Bureau of Weights and Measures in 1892–93, with the collaboration of the bureau, is confirmed within less than one ten-millionth part. In view of the fundamental importance of the matter in spectroscopy, we give here an abstract of the paper.

The mean from three independent determinations by Michelson, by the interference methods he devised, was inferred from their accordance to have a precision of about one half-millionth, which would now seem to have been an underestimate.

Researches by Messrs. Perot and Fabry on interference produced with silver films had led them to new methods which seem superior to the earlier procedure in ease, rapidity, and precision. Accordingly the International Committee on Weights and Measures added to their programme a new measurement of the meter in terms of wave-lengths, in collaboration with Messrs. Perot and Fabry. In the meantime the adoption by the Internationnational Union for Solar Research of the wave-length of the red cadmium line as the basis for spectroscopic measurements increased the importance of the work.

Two operations are involved: (1) the exact determination of the number of wave-lengths and fractions of a wave-length contained in a bar about one meter long; (2) a comparison of this bar with the international prototype.

The bar was of invar, U-shaped in section, 5 cm square on the outside with an interior space 3x3 cm through which a beam of light could be passed; at the ends of the bar parallel silver-on-glass mirrors were attached in the manner previously used by Fabry and Perot. Lines were traced on the upper faces of the mirrors, very close to the edge from which two could be chosen separated by very nearly one meter; this distance was the one measured in wave-lengths.

It was not possible to determine directly the whole number of waves, n (3,103,800), as interference cannot be produced with such a large difference

of path, so that an intermediate standard of length 6.25 cm was selected, which was measured in terms of wave-lengths, and then compared optically with a standard of about twice its length, and so on until the comparison was made for the entire length of one meter. In so doing, the standards were placed one behind the other with their axes in line. The two thin plates serving as compensators were placed at one side and one set of the mirrors permitted us to pass the light at will through any two standards in discussion, and through a thin plate. The order of operations was as follows: the determination of the order of interference in red cadmium of the 6.25 cm standard by observation of the coincidences of red and green, and measurement of the diameter of the first red ring visible; successive comparisons with two thin plates, standardized at the same moment, of each standard with the double of the preceding standard, i. e., (2×6.25 cm) with 12.5 cm; (2×12.5) with 25 cm; (2×25) with 50 cm; (2×50) with 100 cm.

The same measures were then made in inverse order to eliminate the influence of a change in each standard between the time of its comparison with the preceding and with the following standard due to any barometric variation—the variations of temperature being practically negligible since the expansion of invar almost exactly neutralizes that of the air.

The measure of the number of wave-lengths n contained in the sum of the distances separating the lines selected on the faces of the plates which terminated the standard of 10 cm, was made by so mounting the plates successively on two standards of about 1 cm and 2 cm that the distances between the marks in the one case should be double that of the other; the distance between the plates on the 2-cm standard less twice that between the plates when mounted on the 1-cm standard will give the length sought for. In practice similar standards can only be approximated, and we accordingly proceeded as follows:

All the dimensions being expressed in wave-lengths, let E and E' be the distances between the plates, D and D' the distances between the marks, in the two standards and let n be the number sought, then

$$D=E+n\,, \qquad D'=E'+n\,.$$

The standard was so constructed that D' differed very little from $2D$. An invar bar was then made with marks sensibly equi-distant, the distance between any two consecutive marks closely approximating D. Consider now three of these marks, which define two intervals, d and d'. By means of a longitudinal comparator the nearly equal lengths D and d, D and d', D' and $d+d'$ are compared and the following equations obtained:

$$E+n=d+e\,,$$
$$E+n=d'+e'\,,$$
$$E'+n=d+d'+e''\,.$$

The very small quantities e, e', e'', are given in microns by measurement with the comparator and reduced to wave-lengths; E and E' are measured optically. By eliminating d and d' we obtain n. In practice, six intervals were used instead of two. The number of equations was then greater than the number of unknowns and they were solved by the method of least squares.

From a series of fifteen measures carried over six intervals the number was found to be 1270.95 wave-lengths of the red ray or 0.81830 mm.

The comparison of the meter with the distance between the marks on the glass plates carried by the 100-cm standard was made at the same time with the optical measures by comparison with a bar drawn from the same ingot of metal, specially constructed, and investigated with the greatest care by the International Bureau of Weights and Measures relatively to the principal standards in use. Its length differed in the month of November by 4μ from that of the meter, and it lengthened in two months (October to December 1906) by only $0.12\ \mu$.

With the wave-lengths reduced to dry air at 760 mm pressure and 15° on the scale of a hydrogen thermometer, the results of the four optical series utilized, out of the seven made, were as follows:

Series 3.....	1 meter = 1,553,164.12,	$\lambda = 0^{\mu}.64384696$
4.....	.16	695
7.....	.22	692
5.....	.02	700
Mean,	1 meter = 1,553,164.13,	$\lambda = 0.64384696$

The mean of the entire seven series, of which three should apparently be set aside is

$$1 \text{ meter} = 1{,}553{,}163.99\,, \qquad \lambda = 0^{\mu}.64384702\,.$$

It is interesting to note the close accordance of these figures with those of Michelson and Benoit, obtained fourteen years earlier. If their values are reduced to a temperature of 15° (hydrogen scale) and to zero humidity (by applying a plausible but somewhat uncertain correction, which was not done at the time), the result is

$$\lambda = 0^{\mu}.64384700\,,$$

as the mean of three measures having a range of sixty-seven units of the last place. Hence the present measures differ from the earlier ones by less than a ten-millionth part of their relative value. Whatever element of chance there may be in this extraordinary agreement, it is obvious that the prototype meter has not varied in the last fourteen years.

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ERRATA

Astrophysical Journal, Vol. **24**, December 1906, in Mr. Very's article on "The Temperature of the Moon":

Page 351, fourth line, *for* only, *read* mainly.

Astrophysical Journal, Vol. **25**, June 1907, in Mr. Ichinohe's article on the "Orbit of the Spectroscopic Binary κ *Cancri*":

Page 317, next to last line, *for* 3.393, *read* 6.393.

Page 318, third line, *for* 3.393, *read* 6.393.

Astrophysical Journal, Vol. **25**, June 1907, in Mr. Ludendorff's article on the "Orbit of the Spectroscopic Binary β *Arietis*":

Page 320, line 16, *for* 32, *read* 321.

Page 321, line 21, *for* which gave values, *read* for which λ 4481 and $H\gamma$ gave values.

Page 324, last line, *for* -7.2, *read* -7.0.

Page 327, sixth line from foot, *for* mean value, *read* mean error.

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THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

DECEMBER 1907

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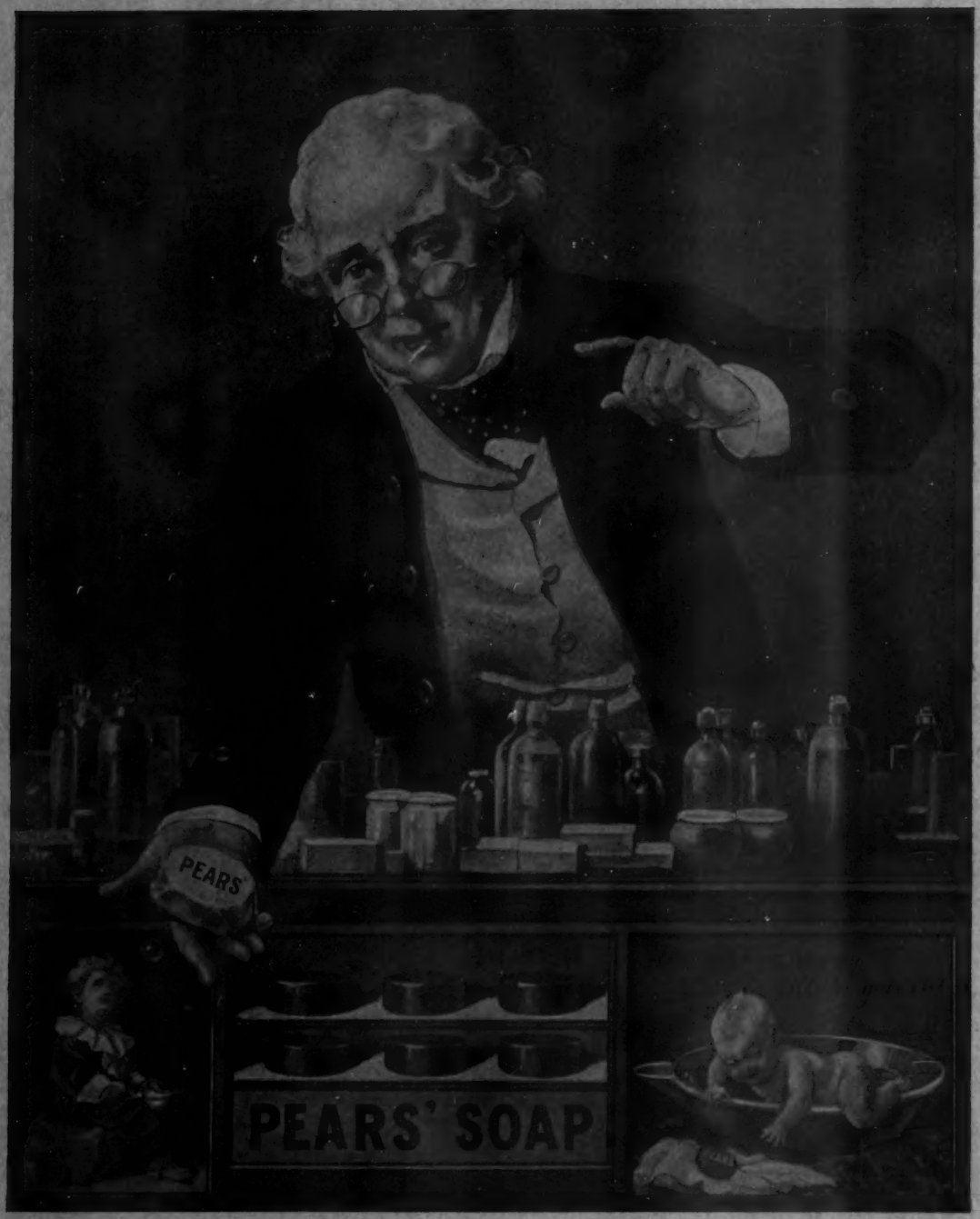

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AND ASTRONOMICAL PHYSICS

PUBLISHED DURING THE MONTHS OF JANUARY, MARCH, APRIL, MAY, JUNE, JULY, SEPTEMBER, OCTOBER, NOVEMBER, AND DECEMBER

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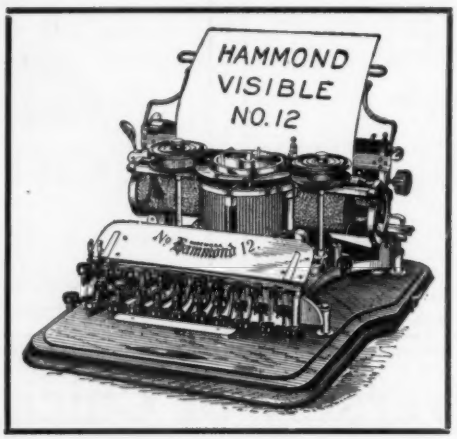

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